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MARCH 14, 2008

MICHAEL W. DOBBINS
CLERK, U.S. DISTRICT COURT

**UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF ILLINOIS
EASTERN DIVISION**

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JUDGE LEFKOW
MAGISTRATE JUDGE KEYS

COMPLAINT

Plaintiff DSM Desotech Inc. (“Desotech”), by and through its attorneys, Mayer Brown LLP and Leydig, Voit & Mayer, Ltd., for its Complaint against 3D Systems Corporation (“3DS”), hereby alleges, on personal knowledge as to allegations concerning itself and upon information and belief as to all other allegations, as follows:

NATURE OF THE ACTION

1. This case arises out of 3DS's unlawful and anticompetitive conduct in the market for large-frame Stereolithography ("SL") machines and in the separate market for resins used in those machines as well as its willful infringement, inducement of infringement, and contributory infringement of two of Desotech's patents related to 3DS's SL equipment, including its large-frame SL machines.

3DS's Anticompetitive Behavior

2. As described more fully below, SL is a process by which a physical object, typically a model or prototype, is created from a computerized machine that uses a laser to solidify liquid resin one layer at a time, in an additive fashion, until the physical object is

eventually formed from the liquid resin. Such prototyping is an essential step in bringing newly designed products from the conceptual stage to actual production, thereby satisfying the demands of increasingly sophisticated consumers and introducing a wide range of new products into everyday life.

3. Resins used in large-frame SL machines are highly innovative, value-added products. Substantial research and development is devoted to creating newer and improved resins. Because the ultimate end product created from the SL process – the model or prototype – is dependent upon the quality and technical specifications of the resin used, there is a strong incentive for resin suppliers to develop a broad array of new resins with improved qualities. Customers have long viewed Desotech as the leader in the SL resin market, largely due to its history of providing innovative and high-performance resins, among other factors.

4. 3DS dominates the market for large-frame SL machines in the United States. Pursuant to an antitrust consent decree entered into in 2002 by 3DS with the United States Department of Justice as a result of 3DS's SL machine monopoly, Sony provided large-frame SL machines to the U.S. market from 2004 to 2006, but no longer does so. Currently, there is no large-frame SL machine manufacturer in the United States other than 3DS.

5. Not content with its monopoly in the market for large-frame SL *machines*, 3DS has engaged in a series of deliberate, anticompetitive acts aimed at substantially foreclosing competition in the market for SL *resins* used in those machines. In 2007, 3DS began conditioning the sale and maintenance of its large-frame SL machines on the purchase of its own SL resins for use in those machines. Since that time, 3DS has expressly refused to sell and service its most recent large-frame SL machine – the Viper™ Pro SLA® System – unless customers exclusively purchase resin from 3DS. 3DS has also informed customers that only

“licensed” or “approved” resins – 3DS’s own resins or those it distributes – can be used in its Viper™ Pro SLA® System, despite the fact that 3DS has never informed customers or competing resin suppliers about such an approval process or the standards used in such a process. By tying large-frame SL equipment and SL resin, 3DS is attempting to foreclose competition in the separate market for SL resins – a market previously characterized by robust competition and comprised of three main suppliers, and several smaller, niche resin suppliers.

6. In addition to this unlawful tying, 3DS’s contracting and licensing practices, described more fully below, constitute an unreasonable restraint of trade and also violate state law.

7. 3DS is also attempting to abuse its monopoly position in large-frame SL machines in an attempt to monopolize the separate market for SL resins used in those machines, which is itself prohibited under antitrust law.

8. Moreover, 3DS has made false, misleading, and disparaging statements about the quality and fitness of use of Desotech’s resins to customers, in violation of state law, and has improperly interfered with prospective economic advantages reasonably anticipated by Desotech.

9. The end goal of 3DS’s anticompetitive conduct is clear: to foreclose competition in the market for resins used in large-frame SL machines. Given 3DS’s current monopoly position in the large-frame SL machine market and its present and growing market share of over 50% in the large-frame SL resin market, this goal is achievable if 3DS’s anticompetitive behavior is not stopped. The substantial amount of research and development required to develop high performance and quality resins, the lack of viable substitutes, and the poor track record of new entrants in the large-frame SL resin market further support the conclusion that 3DS’s anticompetitive goal of substantial foreclosure could become reality.

10. As a result of this substantial foreclosure of competition in the resin market for large-frame SL machines, competition in the resin supply market will no longer exist. As the sole supplier of resin for large-frame SL machines, 3DS will then be able to raise prices and restrict output, thereby harming overall consumer welfare in the market for SL resin.

3DS's Patent Infringement

11. In addition to the anticompetitive conduct described above, 3DS infringes Desotech's SL equipment patents covering the recoating technology used in 3DS's SL equipment, including 3DS's large-frame SL machines.

12. As detailed below, 3DS's SL machines are used to create solid three-dimensional products from liquid plastic resin. 3DS's SL machines use a vat of liquid resin in which a moving platform is positioned. The three-dimensional products are formed on the moving platform by a series of sequential steps. The moving platform is positioned below the surface of the liquid resin in the vat. A moving blade system containing a reservoir of the liquid resin then passes above the platform applying resin as necessary to maintain a uniform surface of resin in the vat above the platform. Then, laser light is applied to the surface of the liquid resin at pre-selected points causing the resin at those points to solidify. The moving platform is lowered such that the newly solidified resin is now below the surface of the liquid resin in the vat. The blade system again passes over the platform providing a uniform liquid resin surface and the process thereafter continues sequentially through these steps until the product is completed. Once formation of the product is completed, the moving platform raises above the surface of the liquid resin remaining in the vat and the completed product can be removed from the platform. 3DS has manufactured and sold a number of SL machines that operate in this manner that infringe patents owned by Desotech with full knowledge of the asserted Desotech patents.

PARTIES

13. Desotech is a Delaware corporation with a principal place of business at 1122 St. Charles Street, Elgin, Illinois, 60120.

14. 3DS is a Delaware corporation with a principal place of business at 333 Three D Systems Circle, Rock Hill, South Carolina, 29730.

15. Both parties transact business in interstate commerce and the activities alleged herein have a substantial effect on interstate commerce.

JURISDICTION & VENUE

16. This Court has subject matter jurisdiction over Desotech's claims under §§ 1 and 2 of the Sherman Act, 15 U.S.C. §§ 1, 2, and §§ 3 and 4 of the Clayton Act, 15 U.S.C. §§ 14, 15 pursuant to 28 U.S.C. §§ 1331 and 1337. This Court has original and exclusive jurisdiction over the subject matter of the patent infringement claim pursuant to 28 U.S.C. § 1338(a).

17. This Court has supplemental jurisdiction over Desotech's state law claims pursuant to 28 U.S.C. § 1367 because those claims are so related to the federal question claims in this action that they form part of the same case or controversy.

18. Venue in this Court is proper for the antitrust, deceptive trade practice, and tort claims pursuant to 28 U.S.C. §§ 1391(b) and (c), and 15 U.S.C. § 22. Venue is proper in this Court for the patent infringement claim under 28 U.S.C. §§ 1391(c) and 1400.

INDUSTRY BACKGROUND & RELEVANT MARKETS

19. Rapid Prototyping/Manufacturing ("RP") is an industry in which a physical object is automatically created from a machine using solid freeform fabrication (*i.e.*, sequential delivery of energy and material in space to create a solid). Once an object's design or specifications are programmed into an RP machine, the machine's software transforms the design into virtual,

horizontal cross-sections and then the machine physically creates the cross-sections in a serial, additive fashion until the final object is finished.

20. RP machines first became widely available in the late 1980s and were initially used to build prototypes and models.

21. SL is a distinct technology within the RP industry. As described in paragraph 12, SL is an additive fabrication process using liquid photopolymer – “resin” – and an Ultraviolet (“UV”) laser – actinic light – to build an object one layer at a time. On each layer, a laser traces a cross-section pattern on the surface of the liquid resin. Exposure to the laser cures (*i.e.*, solidifies) the pattern traced on the resin, which is adhered to the layer below. Specifically, after a pattern has been traced, the platform on which it sits descends by a single layer of thickness and a resin-filled blade sweeps across the cross-section, recoating it with a new layer of resin, which is then again traced and cured by the UV laser. A complete, three-dimensional object is eventually formed by this layer-by-layer process. After the object is formed, it is typically cleaned by immersion in a chemical bath and then further cured in a UV oven.

22. Although other RP technologies exist, they do not compete with large-frame SL machines, which are used to make large-scale parts and products that cannot technologically, economically, or quickly be made by the manufacture and assembly of smaller, constituent parts. For example, other RP technologies such as Laser Sintering (“LS”) or Fused Deposition Modeling (“FDM”) are not viable alternatives to large-frame SL machines. LS does not presently produce products of similar quality and FDM is neither fast nor cost effective on a large scale, as is demanded by most SL customers, particularly service bureaus (*i.e.*, firms hired by a company or individual – either on a regular or one-time basis – to build a product or prototype). Moreover, Digital Light Processing (“DLP”) machines and 3D printers do not match

the substantial variety and performance (*e.g.*, clarity) of resin materials that can be used in the SL process. SL allows over forty resins to be used, thereby permitting a much broader range of end-products than can be produced under DLP or with 3D printers. Large-frame SL machines, therefore, provide the customer with the versatility to participate in multiple end uses and thereby create parts with a wide range of material characteristics and performance qualities. Such benefits could only be replicated by owning numerous other RP technology machines – an option that is neither cost-efficient nor practical for customers.

23. A large-frame SL machine typically includes a vat to store the resin, a built-in computer terminal (and software), a laser, and metal framing, among other components. It is approximately the size of a large-entertainment center and has the following approximate dimensions: 75 in. (width) x 60 in. (depth) x 80 in. (height).

24. 3DS currently dominates the market for large-frame SL machines in the United States.

25. Although, as alleged in paragraph 4, Sony temporarily entered the large-frame SL machine market in the United States in 2004 pursuant to a mandatory patent license resulting from an antitrust consent decree 3DS entered into with the United States Department of Justice, Sony exited the United States market by 2006. The number of Sony manufactured large-frame SL machines currently in the United States market is trivial.

26. The two relevant product markets for this action are: 1) large-frame SL machines; and 2) resins used in those machines.

27. The relevant geographic market for this action is the United States.

28. Customers view SL machines and the resins used in those machines as two distinct products. Many resin purchasers/owners of large-frame SL machines currently buy resin

from resin suppliers other than 3DS, the sole manufacturer of large-frame SL machines in the United States. As described below, resin suppliers compete vigorously for business by continually offering new, improved resins. Customers have long viewed Desotech as the industry leader in offering innovative, higher-performance resins allowing a broader array of end products to be created.

3DS's DOMINANCE OF THE LARGE-FRAME SL MACHINE MARKET

29. 3DS has historically maintained a monopoly in and dominated the large-frame SL machine market in the United States. Even when Sony was in the market during the brief period from 2004-2006, its share of the market was trivial. 3DS is the only current manufacturer of large-frame SL machines in the United States.

30. 3DS's first large-frame SL machine – the SLA® 500 System – was sold around 1992. Almost six years later, around 1998, 3DS introduced another large-frame machine, the SLA® 5000 System (“SLA 5000”). In 1999, 3DS launched its SLA® 7000 System (“SLA 7000”).

The Viper™ Pro SLA ® System

31. In October 2004, 3DS introduced a new model large-frame SL machine: the Viper™ Pro SLA® System (“Viper Pro”). The Viper Pro was a large-frame version of 3DS's Viper™ machine, which is a small-frame machine that was touted as having improved accuracy and resolution.

32. 3DS's launch of the Viper Pro was consistent with its pattern of behavior when it introduced previous models of large-frame SL machines. For example, 3DS promoted regular upgrades containing features presented as technological innovations that did not work and were not demanded by customers. 3DS did not fully disclose to customers how it intended for those

features to operate. As an example, 3DS never informed customers that the radio frequency identification (“RFID”) feature on the Viper Pro could be used to exclude competing resin suppliers. And 3DS has pushed out of circulation previous models that do not contain the new features.

33. Not only has 3DS followed this same pattern with the launch of the Viper Pro, but it has gone further by employing new Viper Pro features, such as the RFID feature, to prevent customers from using Desotech’s Somos® (“Somos”) brand of resins even though there is no reason for, nor benefit to the customer in, making the features mandatory and using the features as a means to exclude competition, even for those purchasers who might actually desire the new features of the Viper Pro.

34. 3DS marketed the Viper Pro as being faster and more accurate than the SLA 7000, its previous large-frame SL machine. While some customers have noticed increased resolution from the SLA 7000, other customers have encountered severe Viper Pro machine quality problems that have been cause for alarm.

35. The new features on the Viper Pro often do not work as promised. For example, 3DS marketed the Viper Pro’s Resin Delivery Module (“RDM”), which feeds resin into the machine during the manufacturing process, as a “new and innovative” feature. In practice, however, for many customers, the RDM has not achieved the operational levels that 3DS promised. Customers have complained about the auto-refill feature of the RDM working only intermittently, vats of resin leaking onto the floor, the failure of the RDM to heat the resin consistently, and the RDM’s inability to circulate the resin to achieve the uniform viscosity that was promised. Customers have also complained about the reliability of the laser used in the Viper Pro, which is a part of the machine that typically should encounter very few problems over

the life of the machine. These severe quality problems, among others, prevent the Viper Pro from operating “lights-out, 24/7” as marketed by 3DS.

36. Substantial barriers to entry exist for potential new manufacturers of large-frame SL machines. The design and manufacture of large-frame SL machines not only requires significant research and development, but also extensive capital investment into developing manufacturing capacity, establishing distribution channels, and hiring a trained sales force, among other items.

37. A key feature of the Viper Pro that 3DS emphasized in its initial marketing campaign for the machine is its RFID material feed system, as previously mentioned. The built-in software that operates the Viper Pro has a feature that prevents the Viper Pro from functioning if the RFID chip in the cap of the jug of resin is not activated or is not recognized by the software.

38. Currently, the Viper Pro works with resin supplied by Desotech. Indeed, many customers prefer to use Somos resins in their Viper Pro machines due to their high performance quality and Desotech’s long history of providing new, innovative resins. For example, Desotech pioneered the development of clear resins that can be used to create see-through models and prototypes, such as WaterClear® 10120 in 2001 and WaterShed® 11120 in 2002.

39. 3DS recently began to activate the RFID feature on Viper Pro machines by having 3DS field engineers download a software update onto the machines. For those Viper Pro machines for which 3DS has not already activated the RFID feature via the software update, it has told its customers that it soon intends to do so.

40. Although many purchasers of Viper Pro machines realized that their machines had the capability for RFID when they purchased the machines, they were informed by 3DS only

that the RFID feature would help improve the machines' performance quality, not that the RFID feature could be used as a method to exclude competing resin suppliers. Customers have informed Desotech that, upon purchasing their Viper Pro machines, they believed they could continue to use Somos resins with their Viper Pro after 3DS activated the RFID feature. Up until 3DS began activating the RFID feature, resin supplied by Desotech was fully compatible with the Viper Pro. Customers who used Somos resins in their Viper Pro machines did not experience any technical problems related to the resin. Nevertheless, 3DS is now using the RFID feature to foreclose competing resin suppliers.

41. Much of the customer migration to the Viper Pro is due not to natural customer demand for the machine or any new feature, but rather to pressure exerted by 3DS on customers to purchase the more expensive Viper Pro, which includes the RFID feature. Notably, 3DS has discontinued manufacturing the SLA 5000 and SLA 7000, making the Viper Pro the only large-frame SL option in the U.S. market for new purchasers.

42. 3DS is also attempting to eliminate existing, older large-frame SL machines from the market. For example, 3DS reached an agreement with a leading SL maintenance contractor, National RP Support, Inc., to stop servicing those SLA 500 machines for which no contractual servicing obligation existed. In addition, 3DS no longer is selling new SLA 5000 and SLA 7000 machines and is removing existing large-frame SL machines from the market by offering substantial incentives to customers to trade-in those machines and purchase a Viper Pro. 3DS's goal is to replace older large-frame SL machines with Viper Pro machines, which contain the RFID feature that can exclude resins from competing resin suppliers.

43. Each customer who purchases a Viper Pro from 3DS enters into a purchase agreement with 3DS for the machine. The purchase agreement contains a clause requiring the

customer not to modify or otherwise alter any of the software contained on the Viper Pro. Any customer modification of the software, including the RFID feature, voids the warranty.

44. As noted above, 3DS has begun activating the RFID feature and stated that it soon intends to activate the RFID feature for Viper Pro machines for which it has not already done so. 3DS has informed customers that any refusal to allow the 3DS field engineer to install the software update will void the customer's warranty on the machine.

45. As described more fully below, 3DS has also informed customers that any attempt by a customer to use resin without a 3DS-approved RFID chip will be futile as the Viper Pro's software will be inoperable and the machine will automatically shut down.

**SL RESIN MARKET AND THE
RELATIONSHIP BETWEEN DESOTECH AND 3DS**

46. As indicated above, there are three main suppliers in the \$20 million resin market for large-frame SL machines in the United States. With annual sales of approximately \$7 million, Desotech accounts for 35% of the resin market for large-frame SL machines in the United States; 3DS's sales of \$10 million represent about 50%; Huntsman's sales of \$2 million represent about 10%; and the remaining \$1 million of sales of smaller, niche suppliers represent about 5% of the market. 3DS's market share has grown while it has engaged in its anticompetitive conduct.

47. The resin market for large-frame SL machines has been highly competitive. Suppliers vigorously compete for customers based on innovation, price, quality, and service, among other factors. Purchasers of SL resin often switch suppliers if they feel that their current supplier is failing to offer an innovative or competitively-priced product.

48. Viper Pro customers who have purchased resin from Desotech have expressly stated a preference for Somos resins, stating that Somos resins are of higher performance quality and work better than 3DS's own resins.

The Parties' Distribution Agreement

49. In 2004, Desotech and 3DS entered into a distribution agreement under which 3DS agreed to distribute Desotech's Somos resins.

50. Under the distribution agreement, 3DS actively began to sell Desotech's high-quality Somos resins to customers using the goodwill associated with the Somos brand as a key selling point. Once these sales were made and a relationship with the large-frame SL customer was established, however, 3DS began to push its own brand of resins on the customer, even if the customer wished to continue using Somos resins.

51. In December 2006, Desotech informed 3DS that it would not renew the distribution agreement with 3DS, due primarily to the fact that 3DS was no longer acting as a true distributor of Desotech's resins, but rather using the relationships with customers gained via the distribution agreement to push its own brand of resin – a position Desotech viewed as incompatible with the distribution agreement.

52. In January 2006, the parties attempted to resolve ongoing intellectual property litigation in Germany between the two companies by agreeing to a Memorandum of Understanding ("MOU") involving the cross-licensing of certain intellectual property owned by each company. During the parties' negotiations of a definitive agreement based on the MOU, 3DS never identified the specific 3DS intellectual property that would be covered by the agreement and instead used the termination of the distribution agreement in December 2006 as an excuse effectively to terminate negotiations altogether. Once it became clear that a definitive

agreement based on the MOU would not be finalized, 3DS began asserting, in May 2007, that Somos resins had to be “licensed” by 3DS for use in the Viper Pro and that 3DS’s grant of such a license was contingent on the continuation of the distribution agreement. When Desotech, seeking to maintain access to Viper Pro customers, inquired with 3DS in November 2007 to review the specific intellectual property that 3DS believed would be subject to such a license and the potential royalty rate that 3DS desired, 3DS, consistent with its past behavior, never identified the precise intellectual property at issue or the royalty rate. Instead – and despite repeated requests from Desotech – 3DS made only vague references to broad categories of intellectual property discussed in earlier negotiations regarding the proposed definitive agreement that was to be based on the MOU and did not provide any details as to the royalty rate 3DS desired.

3DS’s Disparagement of Desotech’s Products

53. As mentioned above, beginning in April 2007, 3DS began claiming that only its own resins and certain Somos resins were “licensed” or “qualified” for use in the Viper Pro, none of which were the newer, more advanced Somos resins that customers repeatedly used and desired.

54. 3DS told customers that Desotech had not done its “due diligence” with respect to certain Somos resins and that those resins were of insufficient quality to run on 3DS’s large-frame SL machines, notwithstanding the fact that many of those resins had been in the market for years, had been used by customers in large-frame SL machines without any quality problems, and 3DS itself had previously distributed some of the exact same resins under its distribution agreement with Desotech.

55. 3DS disparaged Desotech's Somos resins to numerous customers by informing them that the resins were no longer "licensed" or "qualified" despite the fact that neither Desotech nor any customers were aware of any licensing or qualification process in existence. When Brian Bauman, Technical Service and Product Manager at Desotech, contacted Steve Hanna, Director of SL Materials at 3DS, in the summer of 2007 seeking information as to any such licensing or qualification process, he received no reply.

EXPRESS PATTERN

56. Beginning in late 2007, 3DS informed Express Pattern Inc., a Desotech customer in Vernon Hills, Illinois, that Express Pattern would not be able to purchase Desotech's newer Somos resins for its Viper Pro and that it could only purchase the older Somos WaterShed® 11120 resin, claiming that the newer Somos resins that Express Pattern desired were not qualified and/or licensed for use on the Viper Pro. This is despite the fact that Express Pattern specifically asked 3DS when it was deciding whether to purchase the Viper Pro if it could use Somos resins with the Viper Pro machine and was expressly told by 3DS that it could use any resins with the machine.

57. In January 2006, Express Pattern entered into a two-year resin purchase contract with Desotech.

58. Express Pattern has spent a substantial amount of money to develop the market for Desotech's latest Somos investment casting resin, ProtoCast™ AF 19120. Based on 3DS's stated intent to activate the RFID feature on Express Pattern's Viper Pro, however, Express Pattern can no longer use this new resin.

59. Express Pattern has expressed to Desotech its desire to continue to purchase Somos resins from Desotech and to enter into a new resin purchase contract upon expiration of the current contract.

DYNACEPT

60. In a May 31, 2007 email from Abe Reichenthal, President and CEO of 3DS, to Jim Reitz, Business Group Manager for Desotech's Somos business, Reichenthal informed Reitz that, under 3DS's view, the installation of Somos resins into the Viper Pro owned by customer Dynacept Company, Inc., would violate 3DS's intellectual property rights.

61. In a June 4, 2007 email from Lee Dockstader, Vice President of 3DS, to David Yarnell, Director of Rapid Prototyping at Dynacept, Dockstader warned Yarnell that using Somos resins in the Viper Pro would cause its software to "time bomb out" and make the machine inoperable, in addition to voiding the machine's warranty.

62. In a June 6, 2007 phone conversation between Mark Primavera at Dynacept and Charlie Kaufmann, Senior Account Manager at Desotech, Primavera complained about the pressure 3DS was exerting on Dynacept to switch from Desotech's Somos resins to 3DS's resins. Primavera also told Kaufman that Desotech's Somos ProtoGen™ O-XT 18420 resin was running much better than 3DS's resin in the Viper Pro. After only two days of running the Viper Pro with Somos 18420 resin, David Yarnell stated that "ProtoGen's faster photospeed and lower shrink is allowing our technicians to run the machine at maximum speed and power" – thereby allowing Dynacept to deliver highly accurate parts with large frame capabilities.

63. In August 2007, Dynacept's Viper Pro stopped working due to equipment issues. When Dynacept contacted 3DS to service the machine, 3DS informed Dynacept that it would not service the machine if Dynacept continued to use non-approved Somos resins.

FURTHER ANTICOMPETITIVE CONDUCT BY 3DS

64. In an attempt to force customers toward the Viper Pro, 3DS has refused to provide technical support for some older, large-frame machines, which do not have the RFID feature.

65. In mid-2007, Lockheed Martin informed 3DS that one of its SLA 500 machines used in wind tunnel testing stopped working due to problems with its laser. Lockheed had been using Desotech resins in the machine for years without any problems.

66. After a significant amount of pressure by 3DS, including 3DS's refusal to sell the Viper Pro machine to Lockheed unless Lockheed agreed to purchase resins exclusively from 3DS and to stop purchasing resins from Desotech, Lockheed agreed to purchase a Viper Pro to replace its SLA 500 machine.

67. Lockheed has informed Desotech that it is disappointed with the quality of its Viper Pro and with the 3DS resins it is required to use in the machine. Lockheed has stated that it would prefer to use Desotech's Somos 12120 resin in its Viper Pro rather than being required by 3DS to use 3DS's resins. In particular, Lockheed has complained to Desotech that 3DS's SI-48 resin has insufficient accuracy, with particularly bad "differential shrink," which is different dimensional changes based on the thickness of the part.

68. In a March 2007 Memorandum of Understanding between Tangible Express, a Utah-based service bureau, and 3DS, regarding the purchase of six dual-vat Viper Pro machines, 3DS expressly required Tangible Express to purchase all of its resin for the six Viper Pro machines directly from 3DS.

69. In August 2007, Desotech had an oral commitment from AP Proto ("APP"), a potential customer and large service bureau in Tulsa, Oklahoma, for nearly 100% of APP's SL resin requirements. After Desotech had not heard from APP for several weeks, Desotech

reached out to APP and was informed that APP recently completed a deal in which 3DS would supply 100% of APP's resin requirements.

70. As part of the deal between APP and 3DS, 3DS required APP to trade-in an older SL machine for a Viper Pro and to purchase its resins exclusively from 3DS rather than Desotech.

71. As alleged above, 3DS has attempted to extinguish the market for older large-frame SL machines by reaching an agreement with National RP Support, an SL maintenance contractor, requiring it to cease servicing and refurbishing all SLA 500 machines not currently covered by an existing maintenance contract. 3DS has also offered substantial incentives for customers to trade-in their older large-frame machines for new Viper Pro machines with the RFID feature. Moreover, 3DS has required National RP Support to buy all parts through 3DS, thereby raising prices for older, larger-frame SL machines.

72. In February 2008, in response to a request from a Desotech customer who wanted to know whether National RP would service its Viper Pro if it installed Somos resins, Dennis Fogle of National RP informed John Schaefer of Desotech that he "made a verbal agreement with 3D[S] that if [3DS] won't support [a Viper Pro using Somos resins], neither will [National RP]."

73. 3DS's anticompetitive conduct also has substantially narrowed the selection of resin available to customers. By limiting Viper Pro customers to 3DS's resin and only *two* older Somos resins, customers who were accustomed to having over *forty* resins to choose from now only have a few choices, thereby negatively impacting their ability to offer their own customers a broader array of end-products.

AFFECTED COMMERCE

74. As alleged above, the United States resin market for large-frame SL machines is approximately \$20 million annually.

75. Due to 3DS's anticompetitive conduct, Desotech alone has already lost approximately \$500,000 in sales. As the base of customers using Viper Pro machine with the RFID feature continues to grow due to 3DS's anticompetitive conduct, the amount of lost sales experienced by Desotech and other resin suppliers will increase.

76. 3DS sells 20-30 new Viper Pro machines per year, with each single-vat machine having a capacity of about 500 kg of resin per year. By being foreclosed from the SL resin market for Viper Pro machines, Desotech and other resin suppliers will also lose a substantial portion of these future sales, from both existing and potential customers. Moreover, the loss of resin business for large-frame SL machines also makes it unattractive to develop new resins and service small-frame customers.

77. 3DS's anticompetitive behavior, in addition to causing direct injury to Desotech, will substantially lessen competition in the entire large-frame SL resin market. 3DS's tactics have already foreclosed a substantial portion of the large-frame SL resin market and have the potential to foreclose even more competition in the large-frame SL resin market, similar to the monopoly position 3DS currently possesses in the large-frame SL machine market. Such substantial foreclosure not only affects existing competition, but also strongly discourages innovation in the development of new resin. It also dissuades potential new entrants from entering the large-frame SL resin market.

78. By foreclosing competition in the large-frame SL resin market and limiting sales only to those resins offered by 3DS, purchasers of large-frame SL machines will no longer have

a choice of suppliers from whom to purchase resin and will have a substantially smaller selection of resins from which to make their end products. Given the lack of viable substitutes and unlikelihood of new entrants, 3DS will be able to raise prices and restrict output, thereby harming overall consumer welfare.

**COUNT I –
§ 1 SHERMAN ACT (TYING)**

79. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

80. 3DS's conduct in conditioning the sale and/or maintenance of its large-frame SL machines on the purchase of its own SL resins constitutes an illegal tying agreement and is a *per se* violation of § 1 of the Sherman Act, 15. U.S.C. § 1, or, in the alternative, is unlawful under the rule of reason, in that any purported pro-competitive justification for the tie is substantially outweighed by the anticompetitive effects in the SL resin market. Moreover, any purported pro-competitive justification can be achieved through alternative means less restrictive of competition.

81. The relevant geographic market is the United States.

82. Large-frame SL machines (*i.e.*, the tying product) and resins for those machines (*i.e.*, the tied product) constitute separate and distinct products. Customers demand the two products separately and 3DS has itself sold the two products separately for years.

83. 3DS has coerced and forced purchasers of its large-frame SL machines to purchase 3DS's own resins rather than the resins of competing resin suppliers, thereby restraining free competition in the market for resin for large-frame SL machines and eliminating the customer's ability to choose its own supplier of large-frame SL resin.

84. 3DS maintains sufficient market power – the ability to raise prices above those charged in a competitive market or to exclude competition – in the market for large-frame SL machines given its patent and other intellectual property related protections, among other factors.

85. 3DS's tying behavior has had, and will continue to have, substantial anticompetitive effects in the market for large-frame SL resins, and will substantially foreclose the large-frame SL resin market to all other large-frame SL resin suppliers. By substantially foreclosing the large-frame SL resin market to competition, 3DS can unilaterally raise prices and reduce output, thereby significantly harming consumer welfare.

86. 3DS has an economic interest in the sales of resin for large-frame SL machines.

87. A substantial amount of interstate commerce has been affected, and will continue to be affected, in the market for large-frame SL resin due to 3DS's tying conduct.

88. As a direct and proximate result of 3DS's tying conduct, Desotech has suffered, and will continue to suffer, substantial injury, both with existing and potential customers.

**COUNT II –
§ 3 CLAYTON ACT (TYING)**

89. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-86 of this Complaint.

90. As alleged above, 3DS conditions the sale and/or maintenance of its large-frame SL machines on the purchase of its own SL resins, in violation of § 3 of the Clayton Act, 15 U.S.C. § 14. The effect of this tie has been to substantially lessen competition in the market for large-frame SL resin in the United States.

91. A substantial amount of interstate commerce has been affected, and will continue to be affected, in the market for large-frame SL resin due to 3DS's tying conduct.

92. As a direct and proximate result of 3DS's tying conduct, Desotech has suffered, and will continue to suffer, substantial injury, both with existing and potential customers.

**COUNT III –
§ 1 SHERMAN ACT (UNREASONABLE RESTRAINT OF TRADE)**

93. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

94. In addition to 3DS conditioning the sale and/or maintenance of its large-frame SL machines on the purchase of its own SL resins, as alleged above, 3DS's conduct in contracting and licensing with its customers constitutes an unreasonable restraint of trade and commerce, in violation of § 1 of the Sherman Act, 15 U.S.C. § 1. In particular, 3DS's unilateral declaration that all machine warranties are void if a customer does not purchase its resins from 3DS and its failure to service a large-frame SL machine until a customer switches its resin orders to 3DS constitute an unreasonable restraint of trade.

95. The contracts and licenses between 3DS and its customers constitute concerted action.

96. A substantial amount of interstate commerce has been affected, and will continue to be affected, in the market for large-frame SL resin due to this unreasonable restraint of trade resulting from 3DS's contracting and licensing practices.

97. As a direct and proximate result of 3DS's conduct, Desotech has suffered, and will continue to suffer, substantial injury, both with existing and potential customers.

**COUNT IV –
§ 2 SHERMAN ACT (ATTEMPTED MONOPOLIZATION)**

98. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

99. The relevant product markets are large-frame SL machines and the resin used in those machines.

100. The relevant geographic market is the United States.

101. 3DS possesses monopoly power in the market for large-frame SL machines given its patent and other intellectual property related protections, among other factors. No other competing provider of large-frame SL machines currently exists in the United States.

102. As alleged above, 3DS has engaged in predatory and anticompetitive behavior by conditioning the sale and/or maintenance of its large-frame SL machines on the purchase of its own SL resins, as well as by its conduct in contracting and licensing with its customers.

103. The specific intent of 3DS in engaging in this behavior is to monopolize the market for resin used in large-frame SL machines.

104. Given 3DS's current monopoly position in the market for large-frame SL machines, and its present and growing control over approximately 50% of the market for large-frame SL resin, there is a dangerous probability of 3DS achieving monopoly power in the market for resin used in large-frame SL machines.

105. A substantial amount of interstate commerce has been affected, and will continue to be affected, in the market for resin for large-frame SL machines due to 3DS's attempt to monopolize that market.

106. As a direct and proximate result of 3DS's conduct, Desotech has suffered, and will continue to suffer, substantial injury, both with existing and potential customers.

**COUNT V –
ILLINOIS ANTITRUST ACT**

107. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-86, 90, 94-95, and 99-104 of this Complaint.

108. As alleged above in Counts I-IV, 3DS's conduct constitutes tying, unreasonable restraint of trade, and attempted monopolization, all of which are *per se* violations of 740 ILCS 10/3, or in the alternative, violations of 740 ILCS 10/3 under the rule of reason.

109. A substantial portion of 3DS's behavior constituting the violations alleged above occurred in the State of Illinois and has had a substantial impact on trade or commerce within the State of Illinois.

110. As a direct and proximate result of 3DS's conduct, Desotech has suffered, and will continue to suffer, substantial injury, with existing and potential customers in the State of Illinois.

**COUNT VI –
ILLINOIS UNIFORM DECEPTIVE TRADE PRACTICES ACT**

111. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

112. As alleged above, in violation of 815 ILCS 510/2(a)(7), 3DS has willfully represented to customers that Desotech's Somos resins are of a particular standard, quality, or grade, namely that they are not "licensed" or "qualified" on the Viper Pro even though no such licensing or qualification standard exists and customers have repeatedly used Somos resins in their Viper Pro without any problems.

113. As alleged above, in violation of 815 ILCS 510/2(a)(8), 3DS has willfully disparaged Desotech's Somos resins to customers by falsely or misleadingly representing that they are not "licensed" or "qualified" on the on the Viper Pro even though no such licensing or qualification standard exists and customers have repeatedly used Somos resins in their Viper Pro without any problems. 3DS has also made additional statements to customers disparaging the quality of Desotech's Somos resins.

114. Express Pattern paid a premium for its Viper Pro machine in return for the right to use non-3DS resins in the machine. 3DS has since informed Express Pattern that it no longer may use the newer Desotech Somos resins that Express Pattern prefers.

115. A substantial portion of 3DS's behavior constituting the violations alleged above occurred in the State of Illinois and has had a substantial impact on trade or commerce within the State of Illinois.

116. As a direct and proximate result of 3DS's conduct, Desotech has suffered, and will continue to suffer, substantial injury, with existing and potential customers in the State of Illinois.

**COUNT VII –
TORTIOUS INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE**

117. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

118. As alleged above, as part of Desotech's continuing efforts to expand its business and customer base, Desotech has valid business relationships and/or expectancies of such with purchasers of resins for large-frame SL machines, including Express Pattern.

119. 3DS has knowledge of these relationships and/or expectancies of such and has intentionally interfered with them causing a termination of the relationships and/or expectancies. In particular, by conditioning the sale and/or maintenance of its large-frame SL machines on the purchase of its own SL resins, 3DS has unlawfully forced customers who would otherwise have purchased their resin from Desotech to purchase their resin instead from 3DS.

120. A substantial portion of 3DS's behavior constituting the violations alleged above occurred in the State of Illinois and has had a substantial impact on trade or commerce within the State of Illinois.

121. As a direct and proximate result of 3DS's conduct, Desotech has suffered, and will continue to suffer, substantial injury with existing and potential customers in the State of Illinois.

COUNT VIII – PATENT INFRINGEMENT

122. Desotech incorporates and realleges, as though fully set forth herein, paragraphs 1-78 of this Complaint.

123. On January 22, 2002, United States Letters Patent 6,340,297 (hereinafter the “‘297 patent”) entitled Solid Imaging Apparatus With Coating Station was duly and legally issued to DSM N.V. By way of a chain of assignments, ownership of the ‘297 patent was transferred to Desotech with full rights to sue for current and past infringement. A copy of the ‘297 patent is attached as Exhibit A to this Complaint.

124. On May 11, 2004, United States Letters Patent 6,733,267 (hereinafter the “‘267 patent”) entitled Solid Imaging Apparatus And Method With Coating Station was duly and legally issued to DSM Desotech Inc. A copy of the ‘267 patent is attached as Exhibit B to this Complaint.

125. Desotech and its predecessor owners in the chain of ownership of the ‘297 and ‘267 patents have complied with the marking requirements of 35 U.S.C. § 287, and Desotech is entitled to damages for patent infringement that have occurred subsequent to issuance of the ‘297 and ‘267 patents within the time limit provided for by 35 U.S.C. § 286.

126. 3DS has infringed and is infringing the ‘297 and ‘267 patents by offering for sale and selling SL equipment, including at least the Viper Pro, SLA 7000 and SLA 5000 apparatuses in this District and, based on information and belief, will continue to do so unless enjoined by this Court.

127. 3DS has: (1) infringed the '297 patent and the '267 patent; (2) actively induced infringement of the '297 patent and the '267 patent by offering for sale and selling at least the identified SL equipment to customers which have then been used by such customers within the scope of the claims of the '297 patent and the '267 patent; and (3) committed acts of contributory infringement of the '297 patent and the '267 patent by offering for sale and selling at least the identified SL equipment to customers which have then been used by such customers within the scope of the claims of the '297 patent and the '267 patent.

128. Defendant's infringements, inducements to infringe, and contributory infringements of the '297 patent and the '267 patent were and are willful and with full knowledge of said Letters Patent, thereby rendering this case exceptional within the meaning of 35 U.S.C. § 285.

129. By its unlawful infringement of the '297 patent and the '267 patent, 3DS has caused, is causing, and, unless such acts and practices are restrained and enjoined by this Court, will continue to cause immediate and irreparable harm to Desotech for which there is no adequate remedy at law, and for which Desotech is entitled to final injunctive relief under 35 U.S.C. § 283. 3DS irreparably injures Desotech each and every day that its unlawful marketing and sales continue in violation of Desotech's exclusive property rights.

130. As a direct and proximate consequence of 3DS's unlawful infringement of the '297 patent and the '267 patent, Desotech has been, is being and, until such acts and practices are enjoined by this Court, will continue to be damaged in its business and property, for which Desotech is entitled to compensatory and treble damage relief under 35 U.S.C. § 284.

JURY DEMAND

Pursuant to Fed. R. Civ. P. 38, Desotech demands a jury on all issues so triable.

PRAYER FOR RELIEF

WHEREFORE, Desotech prays that this Court:

- A. Enter a judgment that 3DS has violated § 1 and § 2 of the Sherman Act, § 3 of the Clayton Act, 740 ILCS 10/3, and 815 ILCS 510/2(a);
- B. Enter a judgment that 3DS has tortiously interfered with Desotech's prospective economic advantage(s);
- C. Enter a judgment that 3DS has infringed United States Letters Patent 6,340,297;
- D. Enter a judgment that 3DS has infringed United States Letters Patent 6,733,267;
- E. Award Desotech treble damages and its costs associated with this action, including attorneys' fees, under § 4 of the Clayton Act and 740 ILCS 10/7(2);
- F. Award Desotech its costs and attorneys' fees under 815 ILCS 510/3;
- G. Award Desotech, on its tort claim, all actual damages, including consequential and incidental damages, as well as punitive damages;
- H. Award Desotech damages, interest and costs pursuant to 35 U.S.C. § 284 for 3DS's patent infringement;
- I. Award Desotech on its patent infringement claim enhanced damages and its attorneys' fees pursuant to 35 U.S.C. §§ 284 and 285;
- J. Enjoin 3DS from engaging in the anticompetitive, deceptive, and tortious conduct alleged herein;
- K. Enjoin 3DS from engaging in the infringing conduct alleged herein;
- L. All such other and further relief that this Court deems just and proper.

Dated: March 14, 2008

Respectfully submitted,

By: /s/ Britt M. Miller

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**JUDGE LEFKOW
MAGISTRATE JUDGE KEYS**

EXHIBIT A



US006340297B1

(12) **United States Patent**
Chapman et al.

(10) **Patent No.:** **US 6,340,297 B1**
(45) **Date of Patent:** ***Jan. 22, 2002**

(54) **SOLID IMAGING APPARATUS WITH COATING STATION**

5,071,337 A 12/1991 Heller et al. 118/620
5,076,974 A * 12/1991 Modrek et al. 264/22

(75) Inventors: **Brian Gregory Chapman**, Elkton, MD (US); **Christian Henning Clausen**, Woodbury, NJ (US); **Daniel James Mickish**, Wilmington; **Eustathios Vassiliou**, Newark, both of DE (US)

(List continued on next page.)

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JP	61-114818	* 6/1986
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(73) Assignee: **DSM N.V.**, Heerlen (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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Automatic Method for Fabricating a Three-Dimensional Plastic Model with Photo-Hardening Polymer, Hideo Kodama, Rev. Sci. Instrum. 52 (11), Nov. 1981, pp 1770-1773.

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Solid Object Generation, Alan J. Hebet, 1982, Society of Photographic Scientists and Engineers, pp. 185-188.

(21) Appl. No.: **09/541,025**

(22) Filed: **Mar. 31, 2000**

Related U.S. Application Data

(63) Continuation of application No. 08/804,449, filed on Feb. 21, 1997, which is a continuation of application No. 07/884,030, filed on May 18, 1992, now Pat. No. 5,626,919, which is a continuation-in-part of application No. 07/804,269, filed on Dec. 5, 1991, now abandoned, which is a continuation of application No. 07/488,095, filed on Mar. 1, 1990, now abandoned.

Primary Examiner—Nam Nguyen

Assistant Examiner—Emmanuel Luk

(74) *Attorney, Agent, or Firm*—Pillsbury Winthrop LLP

(51) **Int. Cl.**⁷ **B29C 35/08**
(52) **U.S. Cl.** **425/174.4; 264/308; 264/401**
(58) **Field of Search** 264/401, 308;
425/174.4

(57)

ABSTRACT

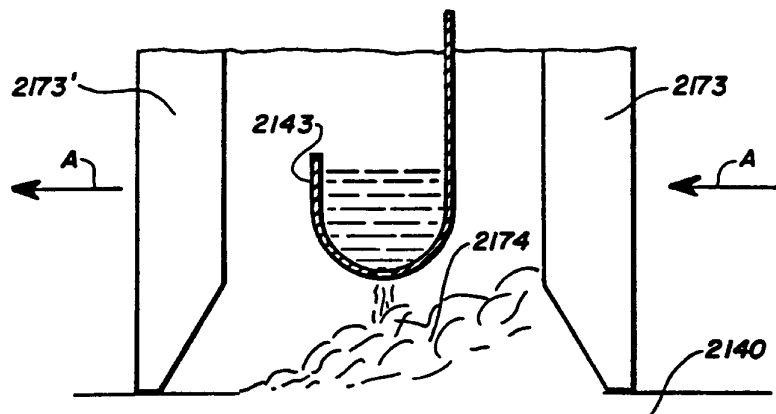
A solid imaging apparatus and method produces an integral three-dimensional object from a multiplicity of cross sectional portions of the object by selectively exposing successive layers of a liquid photoformable composition to actinic radiation. The apparatus includes a vessel for containing the composition so as to present a free surface, and a movable platform disposed within the vessel below the free surface. Part of the composition is transferred above the free surface by lowering and raising a dispenser at predetermined positions located away from the platform. A doctor blade contacts the composition transferred above the free surface, and then moves over the platform to form a substantially uniform layer of the composition.

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12 Claims, 7 Drawing Sheets



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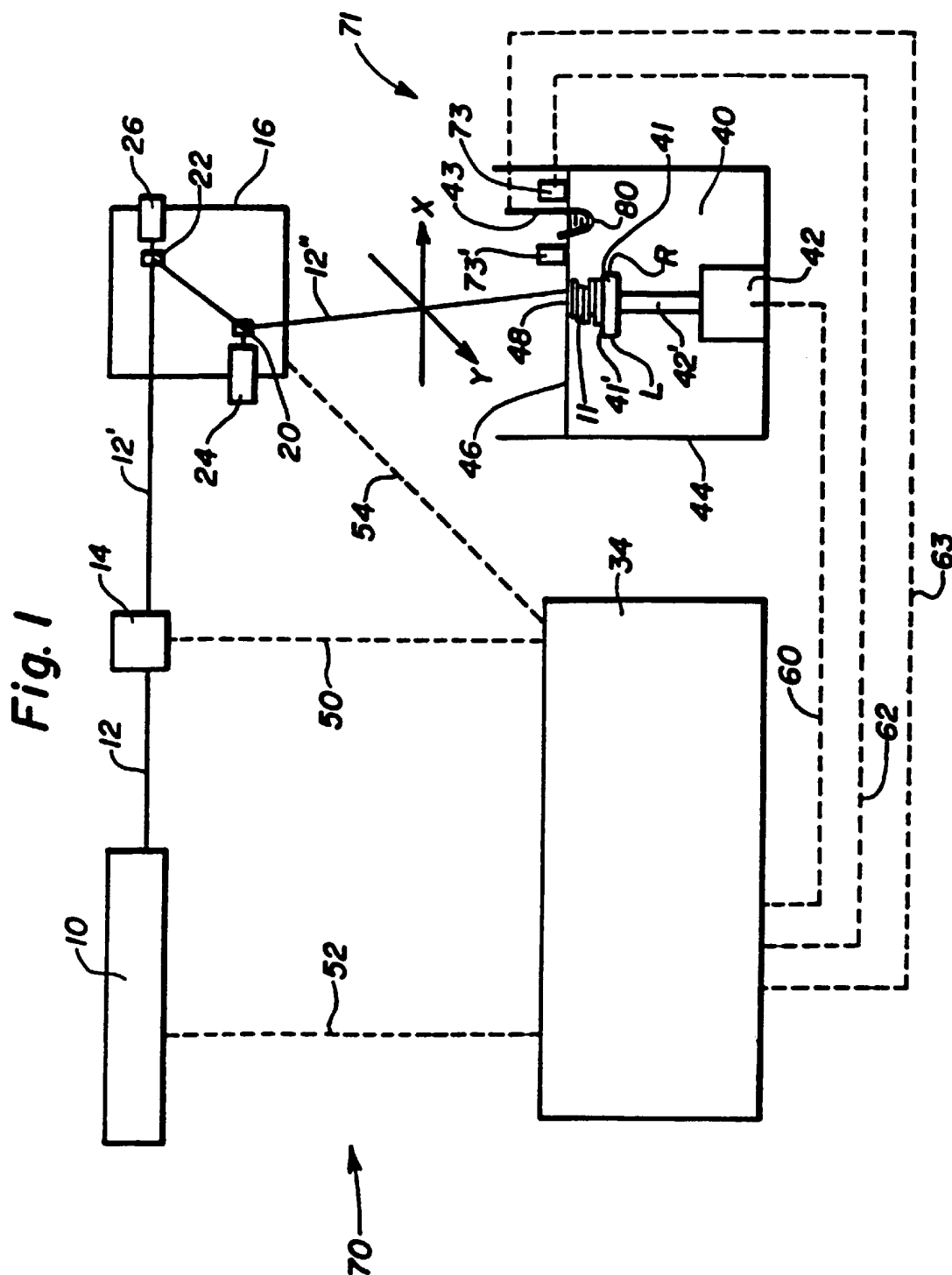
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Fig. 2

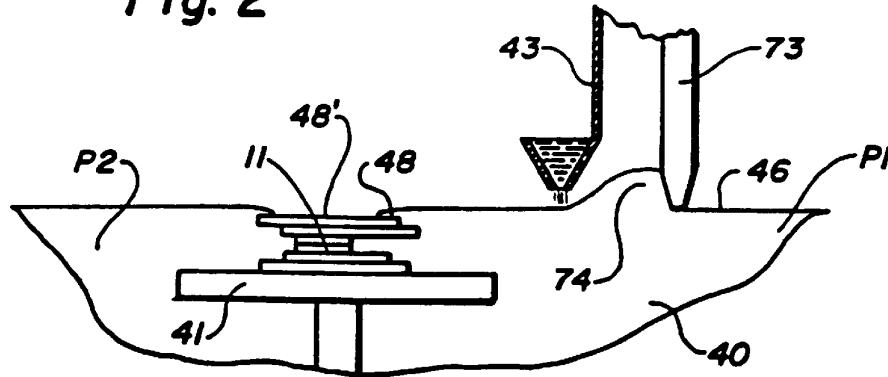


Fig. 3

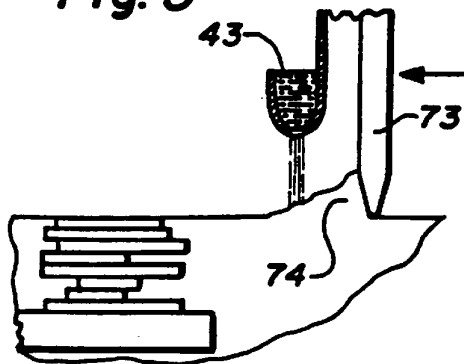


Fig. 4a

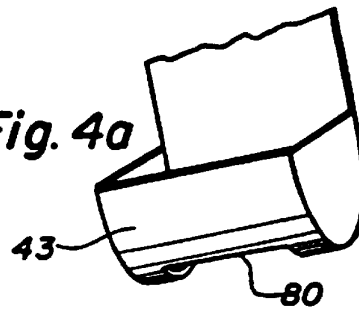


Fig. 4b

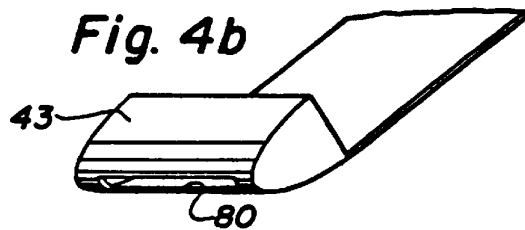


Fig. 5

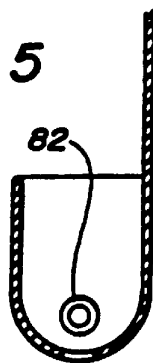
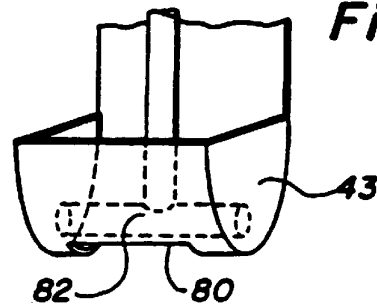


Fig. 6



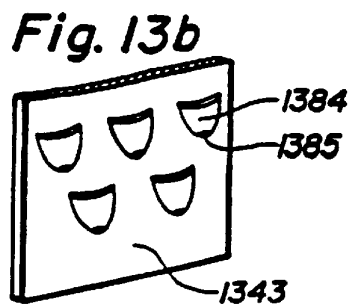
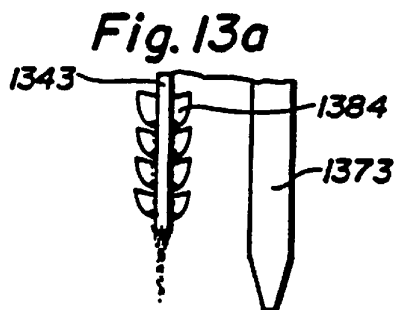
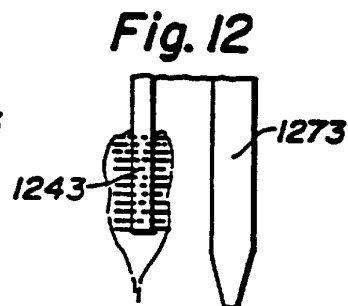
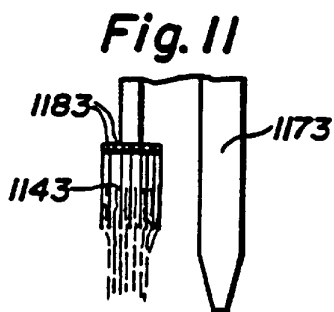
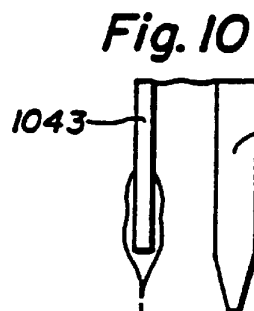
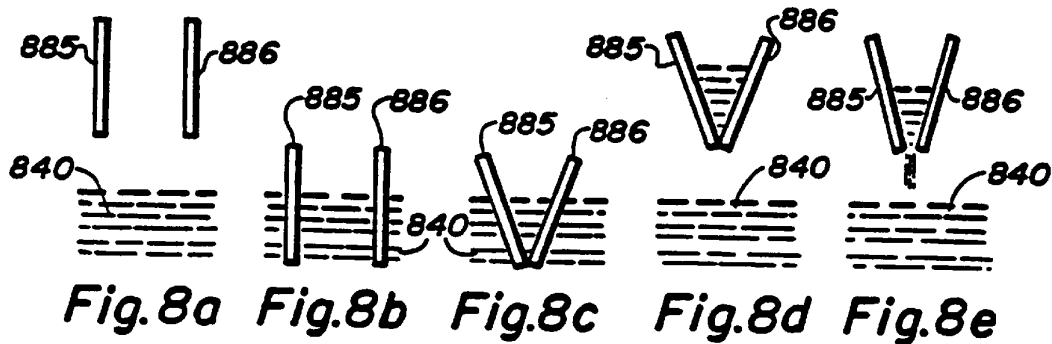
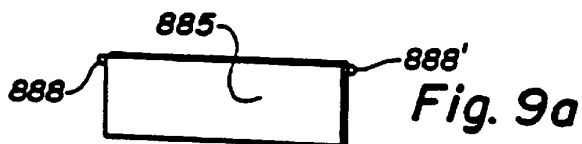
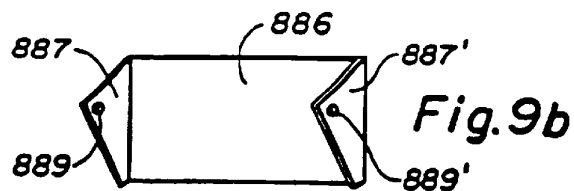
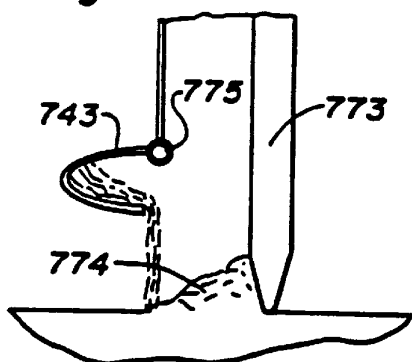
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Fig. 7



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Fig. 14a

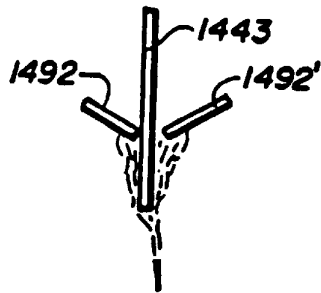


Fig. 14b

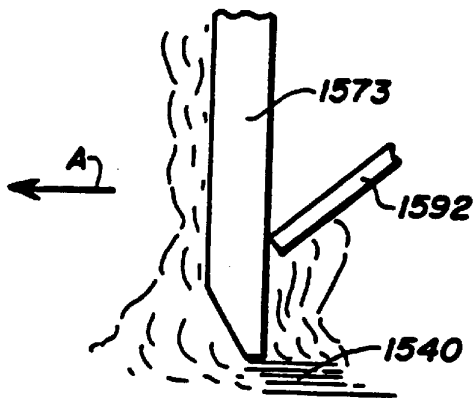
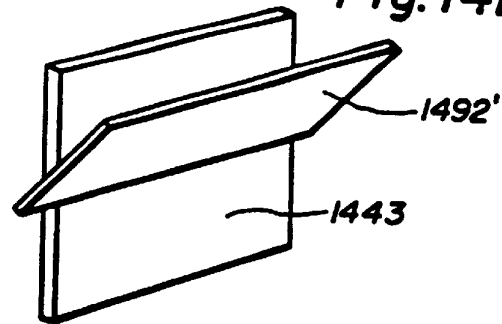


Fig. 15a

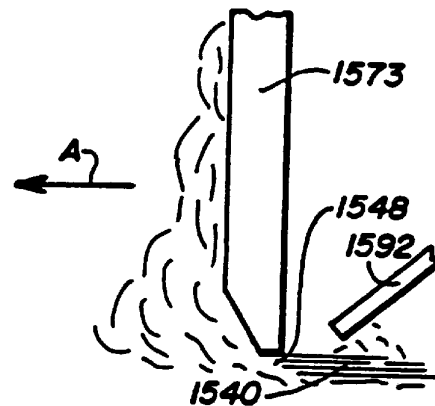


Fig. 15b

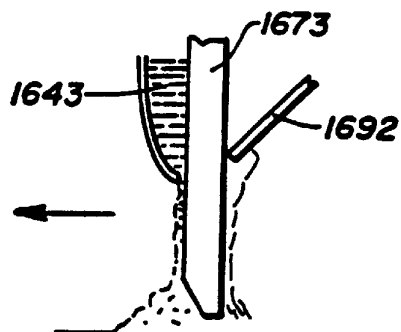


Fig. 16a

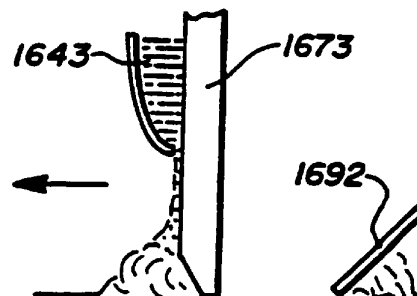


Fig. 16b

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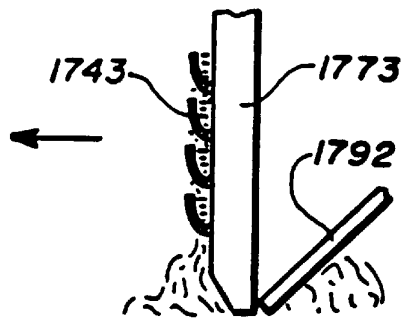


Fig. 17a

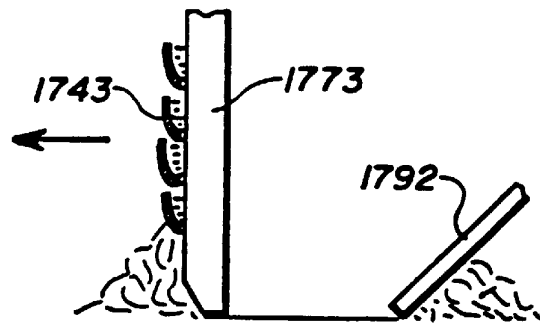


Fig. 17b

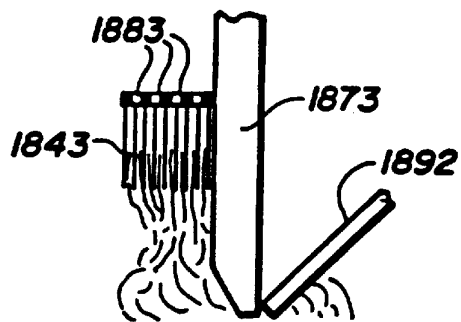


Fig. 18

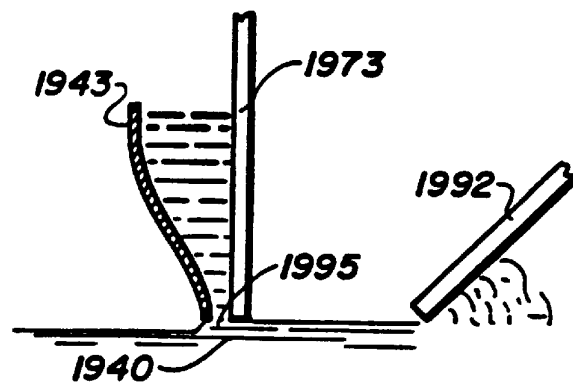


Fig. 19

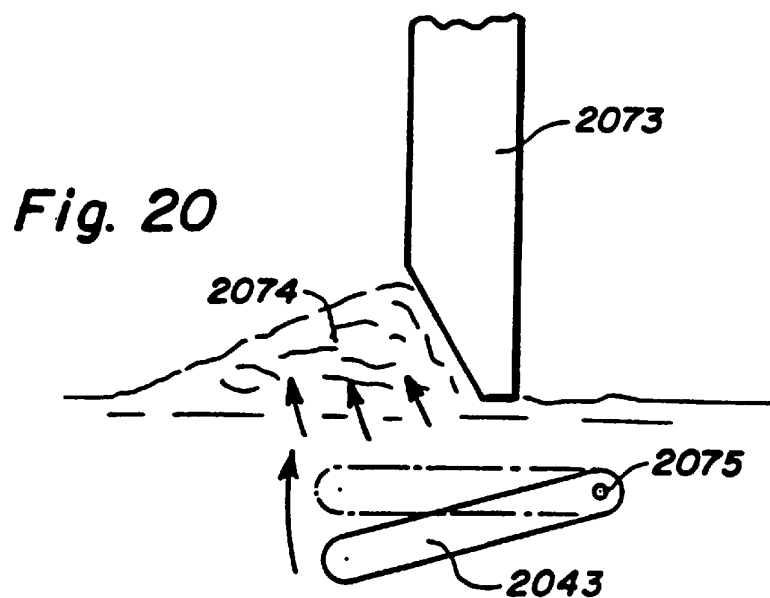


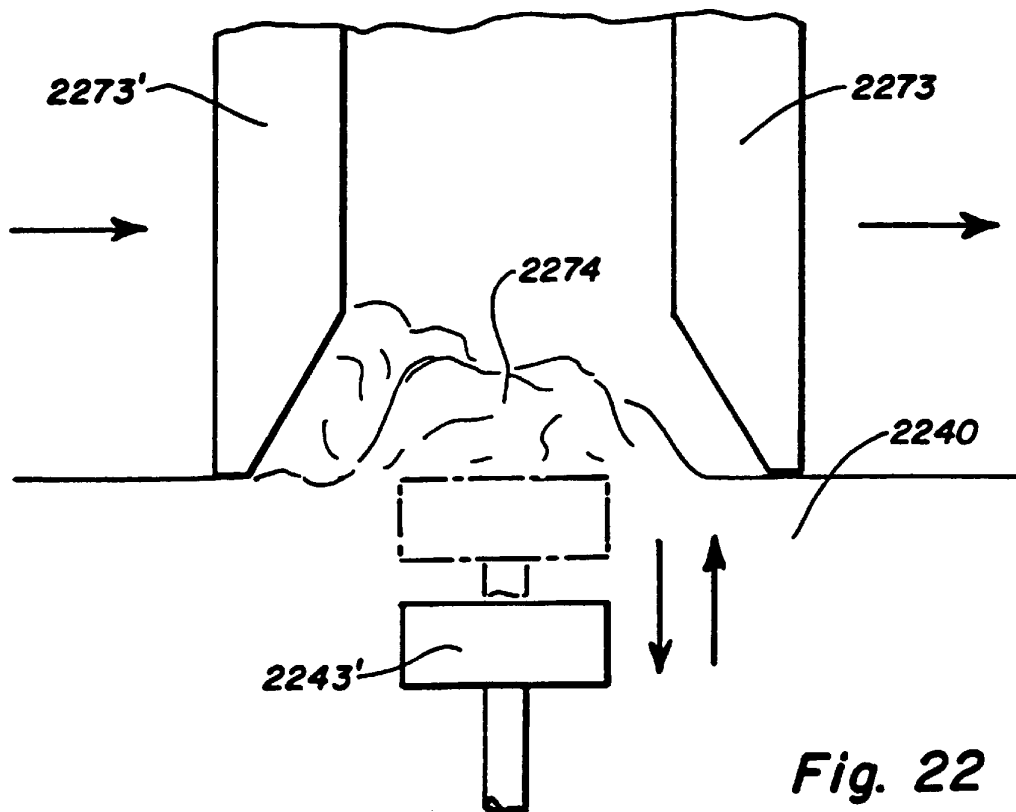
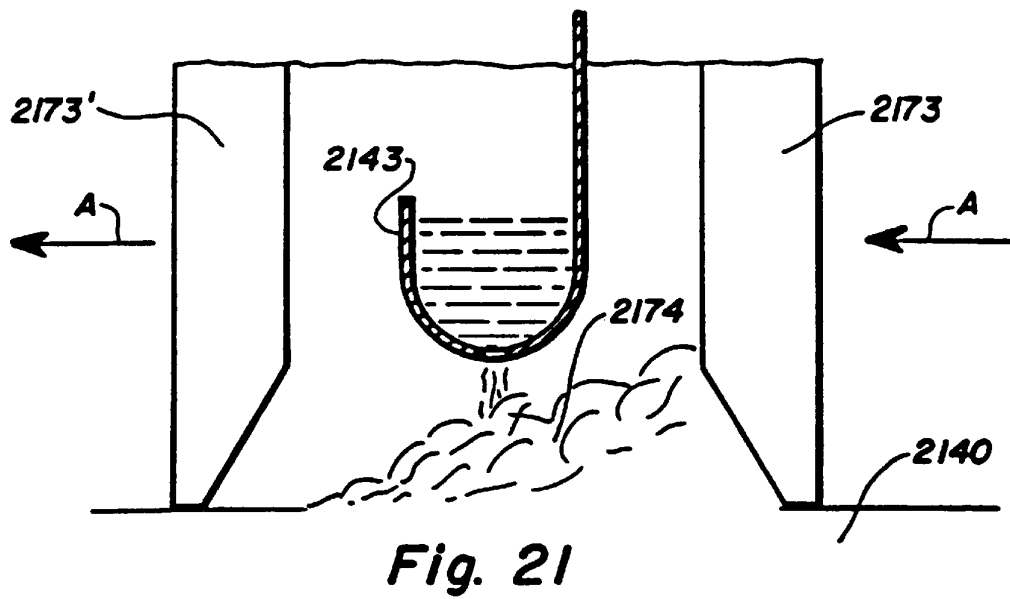
Fig. 20

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**SOLID IMAGING APPARATUS WITH
COATING STATION****CROSS REFERENCE TO RELATED
APPLICATIONS**

This is a Continuation of: National Appln. No. 08/804,449 filed Feb. 21, 1997.

This is a continuation of application Ser. No. 07/884,030 filed May 18, 1992 now U.S. Pat. No. 5,626,919, which is a continuation-in-part of application Ser. No. 07/804,269, filed Dec. 5, 1991, now abandoned, which is a continuation of application Ser. No. 07/488,095, filed Mar. 1, 1990, now abandoned.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

This invention pertains to a solid imaging method and apparatus for fabricating an integral three-dimensional object from a multiplicity of cross sectional portions of the object. More particularly, the cross sectional portions correspond to solidified portions of contiguous layers of a photoformable composition. The method and apparatus use a dispenser in a coating station, which transfers part of the photoformable composition over the free surface of the composition so that a doctor blade may produce a uniform liquid layer.

2. Description of Related Art

Many systems for production of three-dimensional modeling by photoforming have been proposed. European Patent Application No. 250,121 filed by Scitex Corporation Ltd., on Jun. 6, 1987, discloses a three-dimensional modeling apparatus using a solidifiable liquid, and provide a good summary of documents pertinent to this art. U.S. Pat. No. 4,575,330, issued to C. W. Hull on Mar. 11, 1986, describes a system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed at a selected surface of a fluid medium capable of altering its physical state in response to appropriate synergistic stimulation by impinging radiation, particle bombardment or chemical reaction. Successive adjacent laminae, representing corresponding successive adjacent cross-sections of the object, are automatically formed and integrated together to provide a step-wise laminar buildup of the desired object, whereby a three-dimensional object is formed and drawn from a substantially planar surface of the fluid medium during the forming process. U.S. Pat. 4,752,498, issued to E. V. Fudim on Jun. 21, 1988, describes an improved method of forming three-dimensional objects, which comprises irradiating an uncured photopolymer by transmitting an effective amount of photopolymer solidifying radiation through a radiation transmitting material which is in contact with the uncured liquid photopolymer. The transmitting material is a material which leaves the irradiated surface capable of further crosslinking so that when a subsequent layer is formed it will adhere thereto. Using this method, multilayer objects can be made.

A publication entitled "Automatic Method for fabricating a three-dimensional plastic model with photohardening polymer" by Hideo Kodama, Rev. Sci. Instrum. 52(11), 1770-1773, November 1981, describes a method for automatic fabrication of a three-dimensional plastic model. The solid model is fabricated by exposing liquid photo-forming polymer to ultraviolet rays, and stacking the cross-sectional solidified layers. A publication entitled "Solid Object Generation" by Alan J. Herbert, Journal of Applied Photographic

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Engineering, 8(4), 185-188, August, 1982, describes an apparatus which can produce a replica of a solid or three-dimensional object much as a photocopier is capable of performing the same task for a two-dimensional object. The apparatus is capable of generating, in photopolymer, simple three-dimensional objects from information stored in computer memory. A good review of the different methods is also given by a more recent publication entitled "A Review of 3D Solid Object Generation" by A. J. Herbert, Journal of Imaging Technology 15: 186-190 (1989).

Most of these approaches relate to the formation of solid sectors of three-dimensional objects in steps by sequential irradiation of areas or volumes sought to be solidified. Various masking techniques are described as well as the use of direct laser writing, i.e., exposing a photoformable composition with a laser beam according to a desired pattern and building a three-dimensional model, layer by layer. In addition to various exposure techniques, several methods of creating thin liquid layers are described which allow both coating a platform initially and coating successive layers previously exposed and solidified.

The aforementioned methods of coating, however, are not capable of ensuring flat uniform layer thickness or of producing such layers quickly, or they do not effectively prevent damage or distortion to previously formed layers during the successive coating process and they involve coating only liquid formulations of preferably low viscosity. Furthermore, they omit to recognize very important parameters involved in the coating process such as the effects of having both solid and liquid regions present during the formation of the thin liquid layers, the effects of fluid flow and rheological characteristics of the liquid, the tendency for thin photoformed layers to easily become distorted by fluid flow during coating, and the effects of weak forces such as hydrogen bonds and substantially stronger forces such as mechanical bonds and vacuum or pressure differential forces on those thin layers and on the part being formed.

The Hull patent, for example, describes a dipping process where a platform is dipped below the distance of one layer in a vat, then brought up to within one layer thickness of the surface of the photoformable liquid. Hull further suggests that low viscosity liquids are preferable but, for other practical reasons, the photoformable liquids are generally high viscosity liquids. Motion of the platform and parts, which have cantilevered or beam regions (unsupported in the Z direction by previous layer sections) within the liquid, creates deflections in the layers, contributing to a lack of tolerance in the finished part. In addition, this method is rather slow.

U.S. Pat. No. 2,775,758, issued to O. J. Munz on Dec. 25, 1956, and the Scitex application describe methods by which the photoformable liquid is introduced into a vat by means of a pump or similar apparatus such that the new liquid level surface forms in one layer thickness over the previously exposed layers. Such methods have the aforementioned disadvantages of the Hull method except that the deflection of the layers during coating is reduced.

The patent issued to Fudim describes the use of a transmitting material to fix the surface of a photopolymer liquid to a desired shape, assumably flat, through which photopolymers of desired thickness are solidified. The transmitting material is usually rigid and either coated or inherently nonadherent to the solidified photopolymer. The methods described by Fudim do not address the problems inherent in separating such a transmitting material from a photopolymer formed in intimate contact with the surface of the transmit-

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ting material. Whereas the effects of chemical bonding may be reduced significantly by suitable coatings or inherently suitable films, the mechanical bonds along with hydrogen bonds, vacuum forces, and the like are still present and in some cases substantial enough to cause damage or distortion to the photopolymer during removal from the transmitting material surface.

Methods utilizing doctor blades and/or material supply mechanisms have been proposed in such publications as Japanese Patent Application Publication numbers 61-114817, 61-114818, and 61-116322. However, these methods require an exact amount of material or photoformable composition to be added in the vessel every time a layer has to be formed. Also, they require the doctor blade or smoothening blade to have a length equal to the width of the vessel in order to properly operate. Because of this, the systems described in these patents have restrictions necessarily confining the photosensitive material between the doctor blade and part of the vessel at all times. Thus, it becomes very difficult to form a uniform layer in one continuous pass of the doctor blade without ending up with an excess or shortage of material at the end of the pass. In other words, the doctored layer may be either lacking a part of it at the end of one doctoring operation or it may have an excess of material, which will be very difficult to redistribute in order to achieve the proper thickness and uniformity, due to the confined nature of the arrangement. Also, the doctor blade has a tendency to create wave motion in the material surrounding the previously exposed layer causing a disturbing effect, particularly on parts of the previously exposed layer which are partially unsupported.

Thus, it is one of the objects of the present invention to provide an apparatus and a method for fabricating an integral three-dimensional object from a multiplicity of cross sectional portions of the object, the cross sectional portions corresponding to solidified portions of contiguous layers of a photoformable liquid composition, in a fast and uniform manner. Another object of the present invention is to provide a gentle way of raising part of the photoformable composition above the surface of said composition and in front of the doctor blade. Use of a pump to recirculate a liquid of the nature used in solid imaging or stereolithography does not present a viable solution because the viscosity and mainly sensitivity of such compositions cause blockage of the paths and seizure of the pumping operation at an unacceptably high rate. Premature polymerization within the higher-shear components of the pump seem to be the most probable cause of this problem.

SUMMARY OF THE INVENTION

The present invention comprises a solid imaging apparatus and method for fabricating an integral three-dimensional object by selectively exposing successive layers of a liquid photoformable composition to actinic radiation. The apparatus includes a vessel for containing the composition so as to present a free surface, and a movable platform disposed within the vessel below the free surface. Part of the composition is transferred above the free surface by lowering and raising a dispenser at predetermined positions located away from the platform. A doctor blade contacts the composition transferred above the free surface, and then moves over the platform to form a substantially uniform layer of the composition.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view showing a preferred embodiment of this invention.

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FIG. 2 is an elevation view showing a part of the coating station including a dispenser employed in the present invention.

FIG. 3 is an elevation view showing a dispenser for dispensing liquid composition.

FIGS. 4a and 4b are perspective views illustrating the embodiment of FIG. 3.

FIG. 5 is an elevation view showing another embodiment of this invention.

FIG. 6 is a perspective view showing the embodiment of FIG. 5.

FIG. 7 is an elevation view showing another dispenser where a pivoting mechanism is utilized for dispensing the liquid.

FIGS. 8a through 8e are elevation views showing another embodiment of this invention.

FIGS. 9a and 9b are perspective views showing another embodiment of the invention.

FIG. 10 is an elevation view showing a different embodiment of the present invention where the dispenser is in the form of a single plate.

FIG. 11 is an elevation view of another embodiment wherein the dispenser is in the form of parallel blades.

FIG. 12 is an elevation view showing the dispenser as a plate having a plurality of bristles attached to its sides so as to have a brush-like configuration.

FIG. 13a is an elevation view showing still another embodiment of the present invention where the dispenser is in the form of a plate having a plurality of pockets on either side.

FIG. 13b is a perspective view illustrating the embodiment of FIG. 13a.

FIG. 14a is an elevation view illustrating the use of wipers to control the dispensing rate of photoformable composition from a plate-like dispenser.

FIG. 14b is a perspective view illustrating the embodiment of FIG. 14a.

FIGS. 15a and 15b are elevation views illustrating another embodiment of the present invention wherein the doctor blade itself serves as the dispenser.

FIGS. 16a, 16b, 17a, 17b and 18 are elevation views illustrating other embodiments of this invention where the dispenser has been incorporated onto the front part of the doctor blade.

FIG. 19 is an elevation view illustrating yet a different embodiment of the present invention where the dispenser and the doctor blade have been combined into a single unit.

FIG. 20 is an elevation view showing another embodiment where the dispenser is always disposed in the liquid and pulsates to form a wave in front of the doctor blade.

FIG. 21 is an elevation view showing an additional preferred embodiment where two doctor blades are utilized, with the dispenser located between the two doctor blades.

FIG. 22 is an elevation view showing another embodiment where two doctor blades are utilized with the dispenser located between the two blades.

FIG. 23 is a schematic elevation view showing an embodiment of the present invention for lowering and raising the dispenser shown in FIG. 2 at predetermined positions and time periods.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed to a solid imaging method and apparatus for fabricating an integral three-

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dimensional object from a multiplicity of cross sectional portions of the object. More particularly, the cross sectional portions correspond to solidified portions of contiguous layers of a photoformable composition. The method and apparatus use a dispenser in a coating station, which transfers part of the photoformable composition over the free surface of the composition so that a doctor blade may produce a uniform liquid layer.

FIG. 1 shows an imaging station or means 70 including a radiation source 10, a modulator 14, a computer 34 and a deflection means 16, preferably in the form of a scanner. There is also provided a coating station 71. Radiation source 10 is preferably a laser, producing a radiation beam 12. In order to produce solid objects at high speed, the imaging station 70 preferably utilizes relatively high power radiation sources 10, such as high power lasers, which may have major bands in the visible, infrared, or ultraviolet regions. For present photospeeds of photoformable compositions, high power is considered to be a power greater than 20 mW, and preferably over 100 mW as measured from the intensity of the radiation beam 12. However, as faster compositions become available, the values of 20 mW and 100 mW for the beam intensity will become lower accordingly, since photospeed of the composition and intensity of the radiation beam have an inverse relation to each other in order to achieve the same results. The selection of a certain type of laser should be coordinated with the selection of the photoformable composition in a way that the sensitivity of the photoformable composition agrees reasonably well with the wavelength of the laser's emission. Other types of radiation means may also be utilized such as electron beams, x-rays, and the like, as long as their energy type is matched with the sensitivity of the photoformable composition, a beam is provided, and the appropriate conditions for their handling are observed according to established ways, well known in the art. Although means may be provided to modify the shape of the beam cross-section to any desirable shape, the ordinary shape is circular, and the profile of the intensity of the beam is gaussian with a maximum at the center of the circular shape.

The radiation beam 12 passes through the modulator 14, preferably an acousto-optical modulator. The modulated radiation beam 12' passes in turn through the deflection means 16 or scanner, which comprises two mirrors 20 and 22, each mirror having an axis (not shown) allowing reflection of the beam to a free surface 46 in X and Y directions, the X and Y directions being perpendicular to each other and parallel to the free surface 46. The mirrors 20 and 22 may rotatably move around their corresponding axes by means of motors 24 and 26, respectively, for controllably deflecting the beam in a vector scanning mode, in the X and Y directions, towards predetermined positions of a photoformable composition 40 contained in a vessel 44 of the coating station 71. As the beam is deflected by the deflection means 16, it assumes an acceleration from zero level to a maximum acceleration, and a velocity from zero level to a maximum constant velocity. The velocity and intensity of the beam remain proportional to each other, so that the exposure remains substantially constant. The beam 12" exposes pre-selected portions of the composition to a substantially constant depth as described below.

For the purpose of this invention, the radiation beam 12" may be not only a focused beam from a laser, but also light from any other light source, modified in a number of different ways. For example, it may be transmitted through any type of variable optical density photomask such as a liquid crystal display, silver halide film, electro-deposited

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mask etc., or reflected off of any variable optical density device, such as a reflective liquid crystal cell. Also, the deflection means may be any other type of scanner, such as a raster scanner, for example.

The coating station 71 comprises a vessel 44 for containing the liquid photoformable composition 40. A substantially flat platform 41 is disposed within the vessel 44 and adapted to be positioned under the free surface 46 of the composition 40. The platform 44 has sides, such as a left L and a right R side. A placement means 42 is provided for controllably varying the distance between the free surface 46 of the composition 40 and the platform 41 through a supporting arm 42'. Although the placement means 42 is shown in FIG. 1 as being fully immersed in the composition 40, it should be understood that it may be preferably positioned outside the vessel, and connected to the platform 41 either by passing the supporting arm 42' through a seal at the bottom of vessel 44, or more preferably by using a bent supporting arm passing around the vessel and through free surface 46 in order to be connected to and support the platform 41. An important part of the invention is a special dispenser 43 located at one side of the platform 41, in front of any type of layering means, and preferably between two doctor blades 73 and 73'. The dispenser 43 is adaptable to be dipped under the free surface 46 of the composition 40 and directly transfer part of the composition 40 above the free surface 46. The transferred part of the composition is used by the doctor blades 73 and 73' to produce a liquid layer 48 on top of the platform 41 or on top of previously photoformed layers. As shown in FIG. 1, communication lines 52, 50, 54, 60, 62, and 63 are also provided for the computer 34 to control the radiation source 10, the modulator 14, the deflection means 16, the placement means 42, the doctor blades 73 and 73', and the dispenser 43, respectively.

In operation of the preferred embodiment of this invention, the radiation means 10 provides a radiation beam 12 having an intensity as aforementioned. The radiation beam 12 passes through a modulator 14, where its intensity may be modulated from a zero intensity level to a maximum intensity level having a value less than that of the unmodulated beam intensity, due to energy losses. The modulated radiation beam 12', having somewhat decreased intensity due to losses, passes in turn through the deflection means 16 having a two-mirror 20 and 22 assembly, each mirror separately driven by a different motor 24 and 26, respectively. Mirror 20 deflects the beam in a X direction, while mirror 22 deflects the beam in a Y direction, the X direction being perpendicular to the Y direction. Electrical feedback regarding the relative movements of the mirrors 20 and 22 is provided by the deflection means 16 to the computer 34 through line 54. This feedback, being correlatable to the velocity and average residence time of the beam 12" on the predetermined portions of the thin layer 48, is processed by the computer 34, and it is fed to the modulation means 14 as a control command through line 50 in order to modulate the intensity of the radiation beam 12, so that the product of the intensity of the beam 12" and the average residence time at each position of the predetermined portions of layer 48 remains substantially constant. Thus, the exposure level, being by definition the product of these two parameters, remains substantially constant. By maintaining the exposure level constant over the predetermined portions of each contiguous thin layer, the thickness of the layers is also kept substantially constant. This correction or compensation is very important, especially at unsupported portions of the thin layers, where swollen edges will appear as a result of overexposure due to the low initial velocity at the edges in

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vector scanning. The higher the intensity of the beam 12", or the higher the photosensitivity of the photoformable composition, the more severe this problem becomes in the absence of means to maintain the exposure level constant. Such exposure control is also necessary in raster scanning or in systems incorporating overscanned vector schemes, the difference being that the edges of the image may be under-exposed due to lack of exposure contribution from adjacent non-exposed regions. In these cases modulation means are utilized to ensure that edge regions of the image receive substantially the same exposure as non-edge regions. In any event, the radiation beam 12" is controllably directed towards the photoformable composition 40.

The platform 41, which has a substantially flat upper surface 41', is initially placed within the vessel 44 in a way that the flat upper surface 41' is contained within the free surface 46 of the composition 40. In sequence, the platform 41 is lowered in the composition 40 by the thickness of the layer 48. The dispenser 43, which is preferably kept at least partially dipped under the free surface 46 of the photoformable composition 40 when not in motion, is raised and starts dispensing liquid composition 40 between the doctor blades 73 and 73'. The doctor blade 73 then produces a uniform liquid layer 48 on top of the substantially flat surface 41' of platform 41. In FIG. 1, the dispenser 43 is shown to be partially dipped in the composition 40 adjacent the right side R of the platform 41. When the doctor blades 73 and 73' and the dispenser 43 reach the left side L of the platform 41 they stop, and the dispenser 43 is preferably at least partially dipped in composition 40 under the free surface 46. Preferably, the dispenser 43 remains completely dipped at this stage. A short time may be allowed, if necessary, for the free surface 46 to reach equilibrium and assume the desired uniformity. At least a portion of the liquid layer 48 is then exposed imagewise by actinic radiation, which preferably is in the form of the laser beam 12".

After this first imaging step, the platform 41 is lowered again by the thickness of the layer 48. The dispenser 43, which was now kept partially dipped under the free surface 46 of the photoformable composition 40 at the left side L of the platform, is raised and starts dispensing liquid composition 40 between the doctor blades 73 and 73'. The doctor blade 73' then produces a uniform liquid layer 48 on top of the platform 41 and previously photoformed layer as the assembly of blades 73 and 73' and dispenser 43 now moves towards the right side R of the platform 41. When the assembly of the doctor blades 73 and 73' and the dispenser 43 reaches the right side R of the platform 41 they stop again, and the dispenser 43 is dipped in the composition 40 under the free surface 46. A short time may be allowed again, if necessary, for the free surface 46 to reach equilibrium and assume the desired uniformity. At least a portion of the liquid layer 48, now being on top of the previously imagewise exposed layer, is exposed imagewise to the laser beam 12a. The above steps are repeated until all contiguous layers have been produced and the three dimensional object has been completed. All the above steps are coordinated by the computer 34 in a conventional manner.

In the present invention, the equilibrium level of the free surface 46 always remains substantially constant, regardless of the distance moved by the platform, because the amount of photoformable composition 40 within the vessel 44 remains the same since no additional composition 40 is added. The composition needed for successive layers 48 is transferred above the free surface 46 by lowering and raising the dispenser 43 at predetermined positions alongside the platform 41. Since the dispenser 43 dips under the free

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surface 46 and directly transfers part of the composition above the free surface 46, the temporary level of the free surface 46 will be lowered, relative to the previous equilibrium level, due to transfer of some of the composition and the dispenser 43 above the free surface 46. However, after the dispenser 43 is again dipped into the composition 40 below this temporary free surface 46, the free surface 46 quickly returns to its equilibrium level. Consequently, the equilibrium level of the free surface 46 will always remain substantially the same, thereby ensuring that the distance between the deflection means 16 and the free surface 46 remains substantially constant. It is critically important that this distance remain substantially constant in order that the laser beam 12" remain focused precisely at the surface 46 of the composition so as to achieve dimensionally photoformed layers. Even the photoformable composition 40 may change in volume upon polymerization by shrinking approximately one (1) percent, in practice such a change in volume is not significant and does not require any fine adjustments in the equilibrium level of the free surface 46 or the adding of additional composition 40, particularly when the mass of the object being fabricated is less than thirty (30) percent of the mass of the composition 40 in the vessel 44. Usually, the mass of the fabricated part is between one (1) and five (5) percent of the mass of the composition in the vessel 44. Du Pont's SOMOS[®] solid imaging materials are sufficiently close to "ideal" such that no fine turning of the equilibrium level of the free surface 46 is necessary during the fabrication process. It is also significant in the present invention that the dispenser 43 allows the temporary level of the free surface 46 to be lowered while the doctor blade 73 moves across the platform 41, so that the doctor blade 73 minimizes any type of wave motion in the composition surrounding the previously exposed layer, thereby preventing any such wave motion from disturbing the previously exposed layer, particularly those parts of the exposed layer which are partially unsupported.

FIG. 2 illustrates the usefulness of the dispenser 43. When the platform 41 is lowered by the thickness of the layer 48, the composition 40 does not form a complete layer on top of previously solidified layers 11. Thus, unless the three-dimensional object has very limited dimensions, only a small part of the surface of the most recently solidified layer is covered by the liquid layer 48, while a remaining part 48' of the surface remains uncoated. Any conventional means may be used to lower and raise the dispenser 43 at predetermined positions and time periods. Such means include but are not limited to motors combined with rails in the form of cams, electromagnets, and the like. One example is illustrated schematically in FIG. 23. In the embodiment shown in FIG. 23, a rail cam 2393 is employed to lower and raise the dispenser 2343 under and above the free surface 2346 of the photoformable composition 2340, respectively. The dispenser 2343 is also shown with dotted lines, adjacent the right side R' of the platform 2341, where it has been lowered due to the shape of the rail cam 2393, the path of which is followed by cam follower 2394. It is understood that the dispenser will also be lowered adjacent the left side L', and raised in the intermediate position as shown by the complete lines.

In operation, referring back to FIGS. 1 and 2, the dispenser 43 is dipped into the photoformable composition 40 and then it is raised above the free surface 46 of the composition 40. As soon as the dispenser 43 is raised above the free surface 46 of the composition 40, the composition 40 from the dispenser 43 starts being dispensed in front of the doctor blade 73, preferably by force of gravity. It is very

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important that there be an abundance **74** of the composition **40** in front of the doctor blade **73** so that a complete layer **48** may be formed. To avoid entrapment of air in the form of air bubbles in the abundance **74** of composition **40** in front of the doctor blade **73**, it is important that the dispenser **43** be raised only slightly above the free surface **46** of the photoformable composition **40**. It has also been found that the continuity of the liquid dispensed as a curtain or extrusion sheet by the dispenser **43** may suffer interruptions and splitting if the distance between the dispenser **43** and the free surface **46** is high. This will depend, however, on the rheological characteristics of the photoformable composition **40**, the characteristics of the dispenser **43**, and other factors. Thus, it is preferable in general that the dispenser **43** be raised by less than 5 mm, more preferable by less than 2 mm, and even more preferable by between 0.5 mm and 1 mm above the free surface **46** of the composition **40**. It should be noted, however, that during dispensing, the gap between the free surface **46** of the composition **40** and the dispenser **43** should be equal to or greater than the gap between the same free surface **46** and the corresponding doctor blade **73**.

After the dispenser **43** has been raised, both the dispenser **43** and the doctor blade **73** move forward with the dispenser **43** leading and the doctor blade **73** following. The distance between the previously solidified layers **11** and the doctor blade **73**, when the doctor blade **73** is passing above the solidified layers **11**, is maintained constant and corresponds to about the thickness of the layer **48**. After a full pass, a short time may be allowed for the surface **46** of the composition **40** to stabilize, after which the step of exposing imagewise is performed. The speed of travel of the assembly of dispenser **43** and doctor blade **73** should be lower than a certain limit in order to avoid air entrapment in the form of bubbles. This limit depends on the rheological and foaming characteristics of the photohardenable composition **40**. With the photohardenable compositions employed by the applicants, speeds of less than 1 inch per second, and preferably about 0.5 inch per second are adequate to cause only minimal air entrapment.

The dispenser **43** may be shaped like a trough as shown in FIGS. **3**, **4a** and **4b**. It has a slot **80** at the bottom so that liquid can freely run through. Depending on viscosity of the composition **40**, the slot **80** can be thinner or wider in order to deliver a proper amount **74** of composition **40** in front of the doctor blade **73**. It may also have the form of a plurality of openings in proximity to each other. During the dipping operation, it is preferable that the dispenser **43** is not dipped completely under the free surface **46** of the composition **40**, so that the composition **40** enters the dispenser **43** through the slot **80**, or in general through the bottom opening in whatever form it might be, and not over the top, in order to avoid air entrapment, especially with compositions of high viscosity. The dipping and raising rates are also important for preventing air entrapment, and should be adjusted depending on the viscosity, surface tension and, in general, the foaming characteristics of the composition **40**. As shown in FIGS. **5** and **6**, a valve **82** may be incorporated in the design of the dispenser **43** so that it can control the slot **80** according to the desired delivery rate for the composition **40**. In this particular example, illustrated in FIGS. **5** and **6**, this valve **82** can comprise just a rod which can be moved closer or further away to slot **80** in order to permit more or less material to go through at the desired rate.

In another embodiment of the present invention, illustrated in FIG. **7**, the dispenser **743** is connected through a hinge **775** so that when the dispenser **743** is to be dipped, it

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is in an upright position so as to accept the liquid photoformable composition **40** within its cavity; however, when it is raised and ready to deliver the liquid composition, it is pivoted and inclined around hinge **775** as shown in FIG. **7**.

FIG. **10** illustrates another embodiment of the invention where the dispenser **1043** in front of the doctor blade **1073** is just a single plate. This arrangement is especially useful when the viscosity of the composition is high enough so that adequate material is attached to blade **1043**. The material is then delivered in front of the doctor blade **1073** by force of gravity.

Still another embodiment is shown in FIG. **1**, where the dispenser **1143** comprises a plurality of parallel plates connected at the top. This arrangement of the dispenser **1143** allows air to leave the system while it is being immersed into the composition and also allows air to enter system when the composition is being disposed through holes **1183** perforated at the top connecting the parallel plates.

Dispenser **1243**, in a different embodiment shown in FIG. **12**, may also have the form of a brush so that it can accommodate more liquid.

Still another form of dispenser **1343** is shown in FIG. **13**. In this case the dispenser **1343** has the form of a plate with a plurality of pockets **1384** having, preferably, holes **1385** at the bottom of each pocket **1384**.

FIGS. **8a** through **8e** illustrate still another embodiment of this invention. In this embodiment there are two plates **885** and **886**, initially substantially parallel to each other. As shown in FIG. **8a**, the plates **885** and **886** are initially outside the liquid. Then (FIG. **8b**) the plates **885** and **886** are dipped into the liquid, while they are still kept substantially parallel to each other. The reason for this parallel configuration is to avoid turbulence and air entrapment within the composition **840** while the dispenser is being dipped. After the plates **885** and **886** have been dipped into the composition **840** (FIG. **8c**), they are pivoted to assume a V shape so that their bottoms meet while the top parts of the plates **885** and **886** still remain open. FIG. **8d** shows the plates **885** and **886** in the V position outside the liquid composition **840**. This is followed by slightly opening the bottom parts of the plates to form a narrow slot and allow the composition to be dispensed through the slot (FIG. **8e**). The configuration of these two plates **885** and **886** is better shown in FIG. **9a** and **9b**. Plate **885** has two pivoting pins **888** and **888'** at the top. Plate **886** has two side walls **887** and **887'** which have in their upper corners holes **889** and **889'** which are adaptable to receive pivots **888** and **888'**. Thus, the two plates **885** and **886** may be assembled in the form of a dispenser, by pivoting plate **885** around pivots **888** and **888'**, which in turn are inserted in holes **889** and **889'**, respectively. The plate **885** may seal the dispenser by closely contacting the walls **887** and **887'**. In this configuration, if so desired, a slot may be formed at the bottom of the plates, or the plates may be arranged to be substantially parallel to each other, or the whole device can be in a closed position and not allow liquid to pass through, when the bottoms of the plates are brought into contact. Leakage of small amounts of liquid through the walls of the plate **886** and the sides of the plate **885** is not of consequence in most instances. Gasketing materials may be used on the sides and bottom of the plate **885**, and/or the walls and bottom of the plate **886**, if desired, for better sealing. The walls **889** and **889'** may be replaced by a flexible or elastic material for connecting the sides of the two plates in a substantially liquid-proof manner. Any conventional mechanism may be used for opening and closing the blades. Such mechanisms may include but are not limited to

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bars, wires, and the like, connected to the plate **885** for controllably changing the position of one plate with respect to the other.

FIGS. **14a** and **14b** illustrate an additional embodiment of this invention, where the dispenser **1443** is in the form of a plate. Wipers **1492** and **1492'** are provided to controllably dispense picked-up composition by wiping such composition downward. Thus, when the plate **1443** has been dipped and raised in front of the doctor blade (the doctor blade is not shown in FIG. **14a** for clarity purposes), the wipers **1492** and **1492'** start moving downward at a desired rate, preferably controlled by the computer **34**. Similar results may be achieved by holding the wipers **1492** and **1492'** at a constant distance from the free surface **46** of the composition **40**, and raising the dispenser plate **1443** at a desired rate. Of course, this rate may be variable to better fit the dispensing requirements of the particular case. FIG. **14b** shows a perspective view of the dispenser **1443** in plate form in combination with one of the wipers **1492'**.

As shown in FIGS. **15a** and **15b**, the doctor blade itself **1573** can be used also as a dispenser. The doctor blade **1573** is dipped into the composition **1540** and then it is raised to its initial position over the free surface of the photoformable composition, as shown in FIG. **15a**. Since the doctor blade is going to form the coating by moving in the direction of arrow **A**, it is desirable to have a wiper **1592** which moves down and wipes off the excess composition gathered on the back side of the doctor blade **1573**. This is to avoid dragging any material behind the doctor blade **1573** and destroying the uniformity of the produced layer. FIG. **15a** shows the wiper **1592** taking off the excess composition. FIG. **15b** shows the same doctor blade **1573** after it has already started doctoring and leveling a layer **1548** of photoformable composition **1540**, while the wiper **1592** has been lowered and positioned around the free surface of the photoformable composition **1540**. A different way to minimize accumulation of excessive amounts of composition on the back side of the doctor blade **1573** is to dip the blade as it is moving, preferably at an angle smaller than 90 degrees, which increases with time and finally assumes a value of substantially 90 degrees before the doctor blade moves on top of the photoformed layers. This angle is the angle formed between the plane substantially containing the front side of the doctor blade and the plane substantially containing the free surface (FIG. **1**) of the photoformable composition.

The dispenser **1643** shown in FIGS. **16a** and **16b** may be part of the doctor blade **1673** and located in the front part of the doctor blade **1673**. The wiper **1692** performs the same task as described in previous embodiments. FIG. **16b** illustrates the doctor blade **1673** after it has been moved from its initial position, and also shows the wiper **1692** in its lower position.

The front of the doctor blade **1743**, as shown in FIGS. **17a** and **17b**, may have pockets similar to the ones shown in FIGS. **13a** and **13b** for the dispenser **1743**. According to this embodiment, the doctor blade **1743** is dipped into the composition and then raised while the wiper **1792** is stationary near the free surface of the photoformable composition so as to immediately wipe off any excess material on the back part of the blade **1743**. It should be understood that the embodiments already described or the ones described below can be combined in part or in whole. For example, in any of these embodiments the wiper may be either stationary or movable.

Another embodiment, shown in FIG. **18**, illustrates the dispenser **1843** being part of and located in front of the

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doctor blade **1873**, while the wiper **1892** is stationary and at the bottom of the doctor blade **1873** when the blade **1873** is in its initial position.

In still another embodiment illustrated in FIG. **19**, the dispenser **1943** and the doctor blade **1973** can be combined into a unit having a common dispensing tip **1995** at the bottom of the combined device. In FIG. **19**, this combined device is shown while it is providing a layer, while the wiper **1992** has already wiped the back of the device and is in a lowered position.

FIG. **20** shows still another embodiment where the dispenser **2043** is in the form of a plate which is continuously dipped into the composition **2040**. The dispenser **2043** is provided with a pivot **2075** around which the plate may give an upward pulse. Just before the doctor blade **2073** starts its movement for producing a layer, the dispenser **2043** provides an upward pulse and produces an abundance of material **2074** in the form of a wave in front of the doctor blade **2073**. Frequently, this amount of material is adequate for a complete layer to be formed. This embodiment works at its best when the platform and the three-dimensional object to be formed are not excessively large.

Two doctor blades **2173** and **2173'** may be used, one on each side of the dispenser **2143**, as illustrated in FIG. **21**, so that a new layer may be produced regardless of the direction in which the doctor blade/dispenser assembly moves. When the assembly moves in the direction of the arrows **A**, the abundance of material is gathered mainly in front of the blade **2173**, and a new layer is formed behind the blade **2173**. Similarly, when the assembly moves in a direction opposite to that of the arrows **A**, the abundance of material is gathered mainly in front of the blade **2173'**, and a new layer is formed behind the blade **2173'**. It is important that when the assembly stops on either side of the platform, the dispenser is dipped in the liquid composition **2140** to be refurnished with a new amount of photoformable composition **2140** for the next cycle, in the opposite direction.

The embodiment illustrated in FIG. **22** also involves a double doctor blade arrangement (**2273** and **2273'**) similar to that shown in FIG. **21**, except that the dispenser **2243'**, in this case, is always disposed in the liquid photoformable composition **2240**. There is one dispenser **2243'** on one side of the platform and one dispenser **2243** (not shown) on the other side of the platform. Their position is located within the composition **2240**, and under the "stop" positions of the doctor blades on either side of the platform. Just before the doctor blades start their travel, the respective dispenser moves quickly upward and forces an abundance of liquid to gather between the two doctor blades. The rest of the operation is substantially the same as in the other embodiments.

In the cases where the dispenser and the doctor blade are separate units, it is often desirable to dip the dispenser in a particular manner. For example, as shown in FIG. **2**, it is often preferable to dip the dispenser **43** at position **P2** while the initial position of the doctor blade **73** is on the other side of the platform at position **P1**. According to this option, the dispenser **43** is moved over to position **P2**, it is dipped at this position in order to receive an adequate amount of composition, then it is raised and brought back in front of the doctor blade **73** at position **P1**. During this movement, the dispenser **43** may continue delivering material over the platform area. On other occasions where the delivery of material can be controlled, such as in the embodiments shown in FIGS. **5**, **6**, **7** or **8**, it may be desirable for the dispenser to start dispensing composition only when it is in

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front of the doctor blade 73 at position P1 and at the same time that the doctor blade 73 is forming the layer. This version of operation may be desirable when higher accuracy and speed are needed since the material received by the dispenser 43 at position P2 is going to be moved back by the doctor blade 73.

In most cases it is desirable for the dispenser 43 to be in the dipped position while exposing the layer, so that material still held by the dispenser will be in the container and will not change the level of the free surface of the composition and of the layer. As mentioned before, it is important for the dispensed liquid to be very close to the free surface of the composition in order to avoid splashing and entrapment of air in the form of bubbles. Of course, one can work under vacuum, thereby making the height at which the dispenser operates immaterial.

Since all these devices are controllable by a computer, one can arrange the delivery cycle as well as their speed of operation in order to obtain maximum efficiency and uniformity. Depending on the viscosity and other properties of the photoformable liquid composition, somewhat different conditions may be needed to obtain optimal results. Sensors such as ultrasonic, infrared, and the like may be used to give feedback to the computer regarding the build-up in front of the doctor blade and regulate, accordingly, the delivery through the above mechanism.

The photoformable compositions which can be used in the practice of the instant invention are any compositions which undergo solidification under exposure to actinic radiation. Such compositions comprise usually but not necessarily a photosensitive material and a photoinitiator. The word "photo" is used here to denote not only light, but also any other type of actinic radiation which may transform a deformable composition, preferably a liquid, to a solid by exposure to such radiation. Cationic or anionic polymerizations, as well as condensation and free radical polymerizations and combinations thereof are examples of such behavior. Cationic polymerizations are preferable, and free radical polymerizations even more preferable. Photoformable compositions containing thermally coalescible materials are of even higher preference.

A liquid thermally coalescible photoformable composition is a composition which solidifies upon exposure to actinic radiation without attaining necessarily its ultimate physical properties, particularly with respect to their adhesive and cohesive characteristics. However, it develops adequate integrity to be handled until such time when further treatment is provided. The composition is considered as coalescible when it comprises particulate matter in dispersed form, which particulate matter undergoes coalescence under a certain set of conditions, such as increased temperature for example. Coalescence is the transformation of a dispersed phase to a cohesive continuous solid phase.

Preferably the photoformable composition comprises a thermally coalescible polymeric cohesive material, a photoformable monomer, and a photoinitiator. Preferably the photoformable material comprises an ethylenically unsaturated monomer. Upon exposure to the actinic radiation, the exposed areas of the photoformable composition must remain thermally coalescible after removing the unexposed areas. This is important to improve both adhesion in the joining surfaces between the layers and cohesion within the layers for a multilayer integral three dimensional object. Actually, cohesive bonds are formed at the joining surfaces by the thermally coalescible material, providing superior properties to the structure of the final three dimensional

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object. It is also very important to prevent substantial overgrowth of infraposed surfaces, as it will be discussed below.

In the case of photoformable compositions which are not based on coalescible materials, post treatment after the exposure step is not required. In the case where a coalescible material is an essential component of the formulation, further heat treatment is needed for the object to attain its ultimate strength. In such cases, when all the layers of the three dimensional object have been formed by the method described above, the unexposed portions of the composition may be removed by any conventional means, such as shaking the object, blowing gas towards the object, and the like. Further removal may be achieved by rinsing the object with poor, noncoalescing solvents. Water, alcohols, and in general polar solvents are poor solvents for non-polar compositions and vice-versa. As long as the solvent under consideration does not extract excessive amounts of materials from the exposed area or cause the object being rinsed to swell within the rinsing time, it is considered to be a poor, non-coalescing solvent. The object then is thermally coalesced in order to develop high cohesive and adhesive strength. This step may be performed in an oven, such as a convection, IR or microwave oven. Optimum temperature and time are dependent on the individual composition. Typically the temperature range is 100°–250° C. and the time range is 5–30 minutes. However, temperature and times outside these regions may be used.

A very important group of thermally coalescible materials are plastisols. Plastisols are fluid mixtures, ranging in viscosity from pourable liquids to heavy pastes, obtained by dispersing fine particle size polymeric resins in nonvolatile liquid thermal plasticizers, i.e., materials which are compatible with the polymer or resin and increase its workability and flexibility but have no substantial solvent activity for the resin or polymer under ordinary conditions of storage (e.g. room conditions). When the plastisol has been formed into a desired shape, e.g., by molding or coating, it can be heated to coalesce the polymeric resin particles and the nonvolatile liquid constituent, thereby forming a homogeneous solid mass. Volatile diluents can be added to plastisol dispersions to modify their viscosity and to achieve desirable handling characteristics in coating or other forming operations.

A dispersion that contains no more than 10% volatile diluent is regarded as a plastisol. Since the plasticizer used in the case of plastisols acts as a plasticizer to solvate the polymer only at temperatures higher than storage temperatures, it may also be called a thermal plasticizer. The most widely used plastisols on a polyvinyl chloride homopolymer in a plasticizer.

The following photohardenable composition was made by mixing thoroughly the following ingredients:

1. Ethoxylated Trimethylol Propane Triacrylate	75.0 g
2. Urethane Acrylate Resin (Sartomer 9610)	75.0 g
3. 2,2-dimethoxy-2-phenylacetophenone	6.0 g
4. Clear Chem-o-sol ® 7557 (made by Whittaker Corp. Providence Chemical Division, East Providence, RI)	225.0 g

An automobile distributor cap of excellent quality was made by using this photohardenable composition, and the method and apparatus as described hereinabove. The double

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doctor blade arrangement with the dispenser as shown in FIG. 21 was used. When the dispenser was at rest on either side of the platform, it was maintained completely immersed under the free surface of the photohardenable composition. During dispensing at the raised position, the dispenser was 1 mm above the free surface of the composition. The slot width was approximately 0.190 inch and the travelling speed 0.5 inch per second. Only a minimal amount of bubbles were observed on the free surface of the composition. No interruptions occurred on either the dispensed liquid or on the layers, which were 0.015 inch thick. After the distributor top was photoformed it was thermally treated in a convection air oven at 165° F. for 15 minutes for the part to achieve its ultimate strength. It should be noted that when the dispenser was raised more than 5 mm above the free surface of the composition, the dispensed liquid in the form of a curtain had interruptions along its width resulting in inadequate coverage of previously photoformed layers.

What is claimed is:

1. A solid imaging apparatus, said apparatus including:
 - (i) a vessel for containing a photoformable composition with a free surface;
 - (ii) a movable platform disposed within said vessel; and
 - (iii) a sub-assembly having
 - (a) two doctor blades; and
 - (b) a movable dispenser;
 wherein said movable dispenser is capable of lifting, at a position between said two doctor blades, an amount of said photoformable composition to a position above said surface.

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2. The apparatus of claim 1, further comprising a radiation source capable of curing said photoformable composition on said platform.

3. The apparatus of claim 1, wherein said movable dispenser is further capable of depositing above said platform at least a portion of said amount of said photoformable composition.

4. The apparatus of claim 3, wherein both said doctor blades are capable of leveling at least part of said at least a portion of said amount of said photoformable composition.

5. The apparatus of claim 1, wherein said dispenser comprises a downwardly facing elongated slot.

6. The apparatus of claim 5, wherein said dispenser lifts said amount of said photoformable composition through said slot.

7. The apparatus of claim 3, wherein said dispenser lifts said amount of said photoformable composition through said slot.

8. The apparatus of claim 3, wherein said dispenser deposits said at least a portion through said slot.

9. The apparatus of claim 7, wherein said dispenser deposits said at least a portion through said slot.

10. The apparatus of claim 1, wherein said dispenser includes at least one of said doctor blades.

11. The apparatus of claim 5, wherein said dispenser includes at least one of said doctor blades.

12. The apparatus of claim 9, wherein said dispenser includes at least one of said doctor blades.

* * * * *

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**JUDGE LEFKOW
MAGISTRATE JUDGE KEYS**

EXHIBIT B

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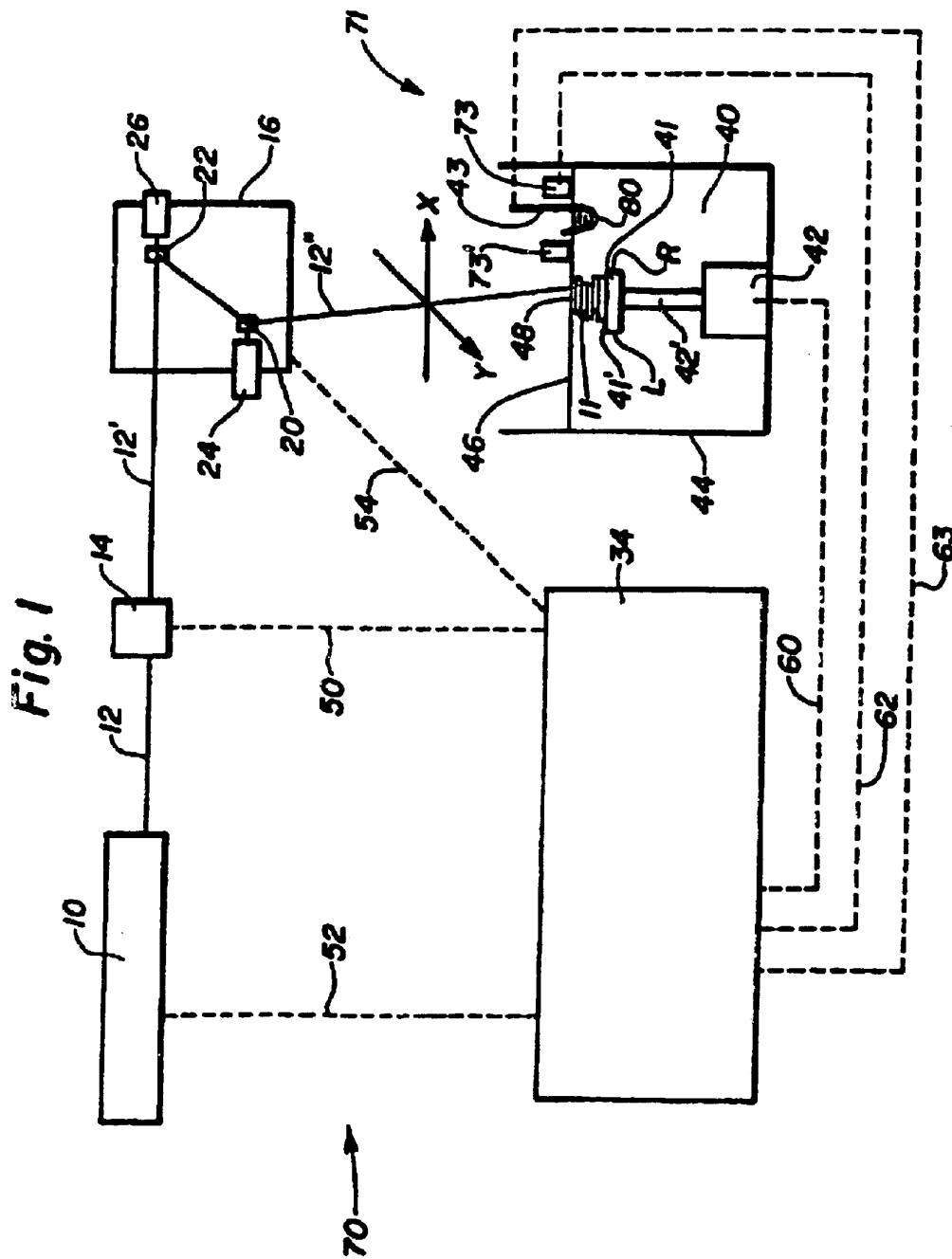
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Fig. 2

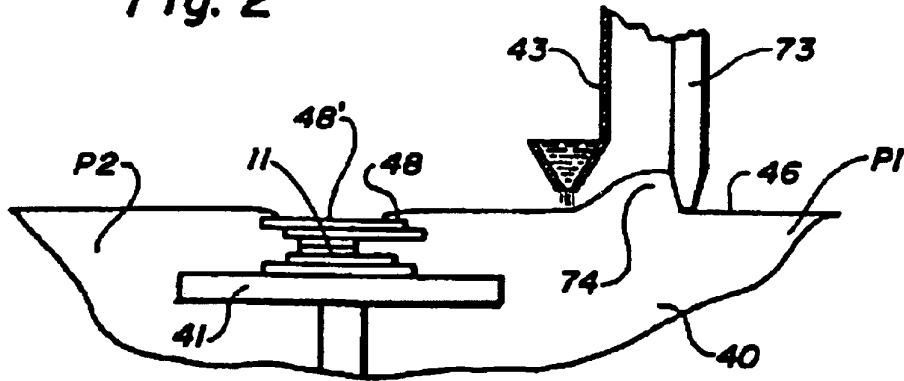


Fig. 3

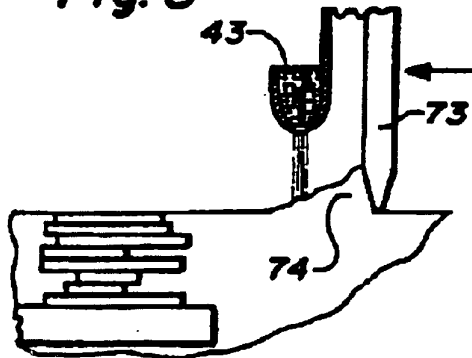


Fig. 4a

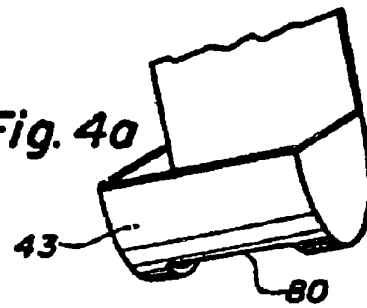


Fig. 4b

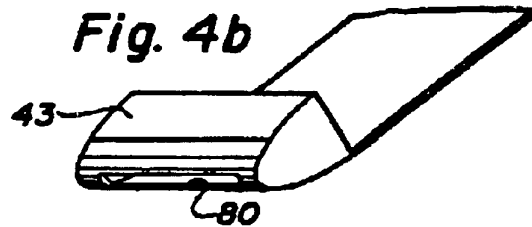


Fig. 5

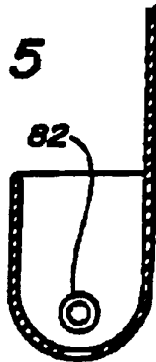
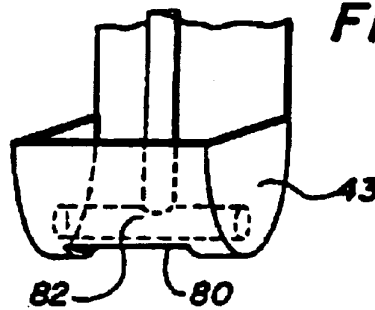


Fig. 6



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Fig. 7

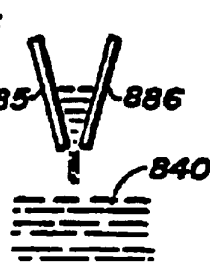
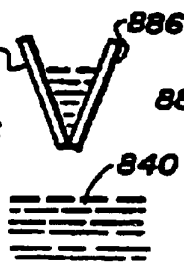
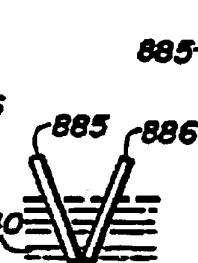
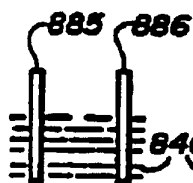
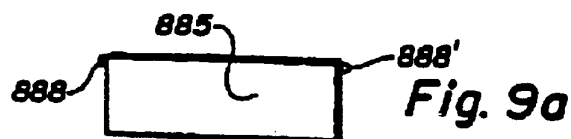
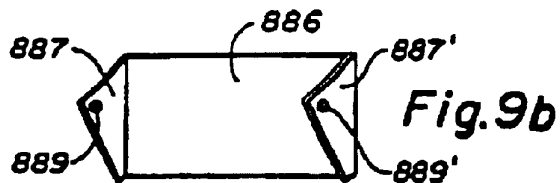
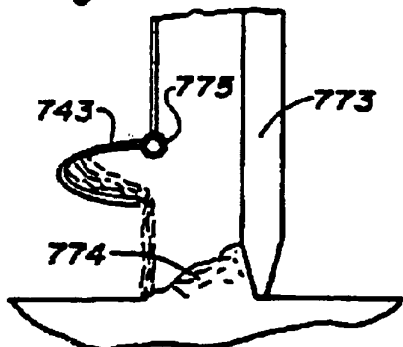


Fig. 8a Fig. 8b Fig. 8c Fig. 8d Fig. 8e

Fig. 10

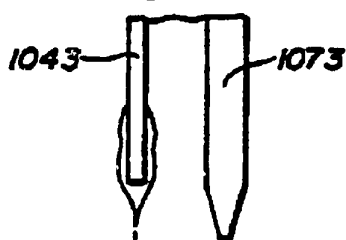


Fig. 11

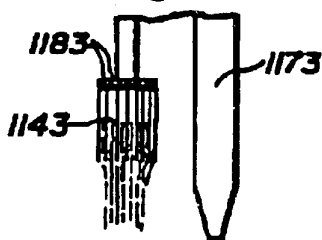


Fig. 12

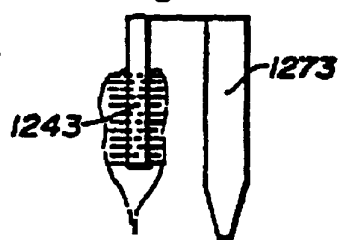


Fig. 13a

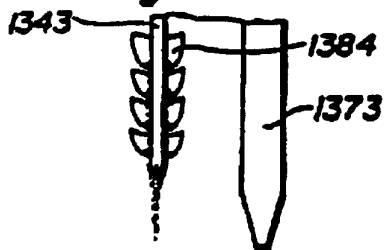
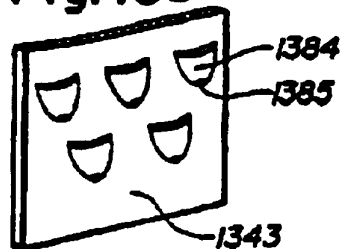


Fig. 13b



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Fig. 14a

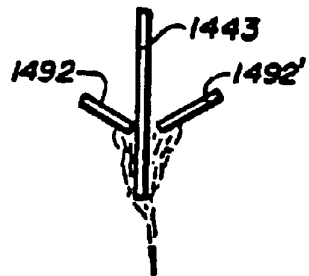


Fig. 14b

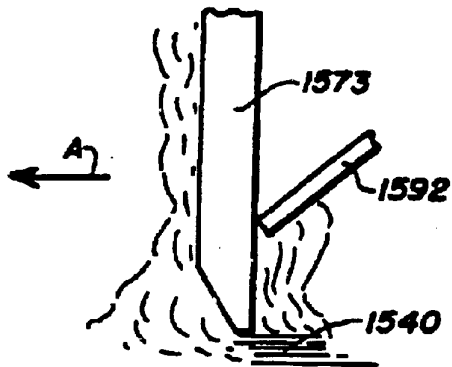
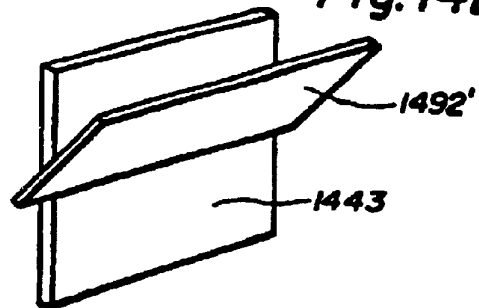


Fig. 15a

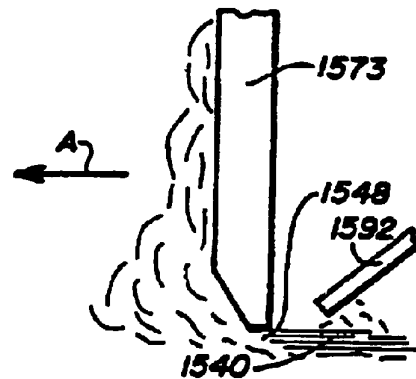


Fig. 15b

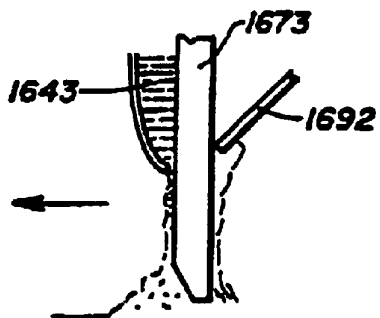


Fig. 16a

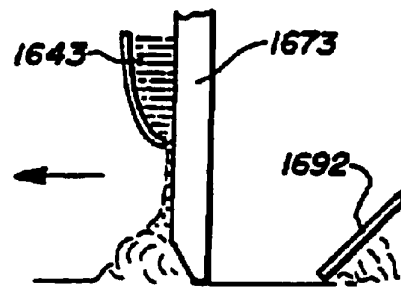


Fig. 16b

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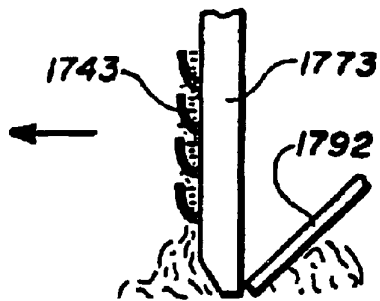


Fig. 17a

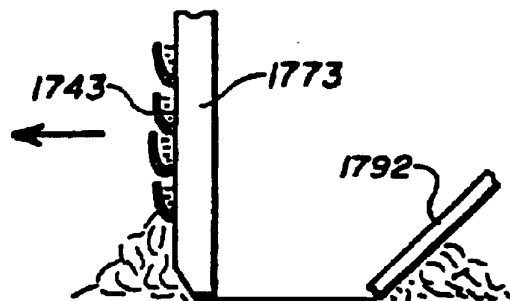


Fig. 17b

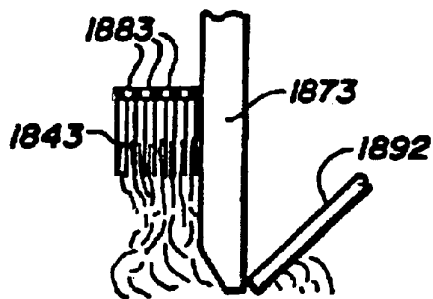


Fig. 18

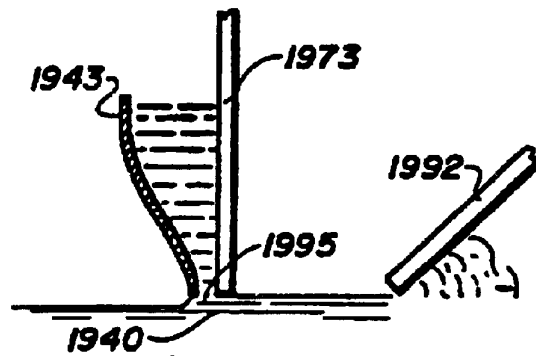


Fig. 19

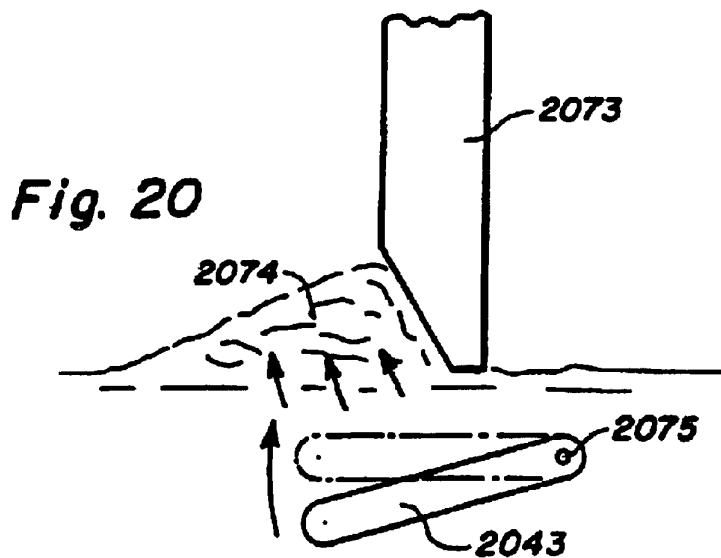


Fig. 20

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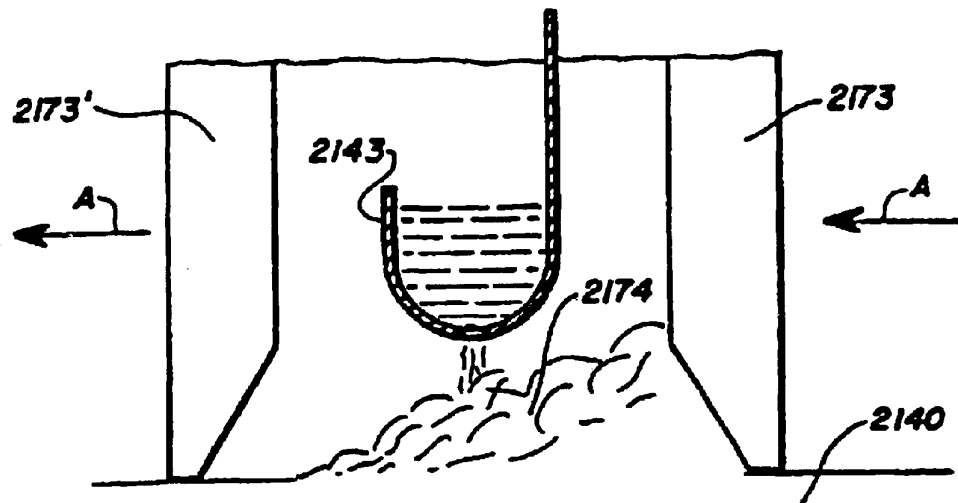


Fig. 21

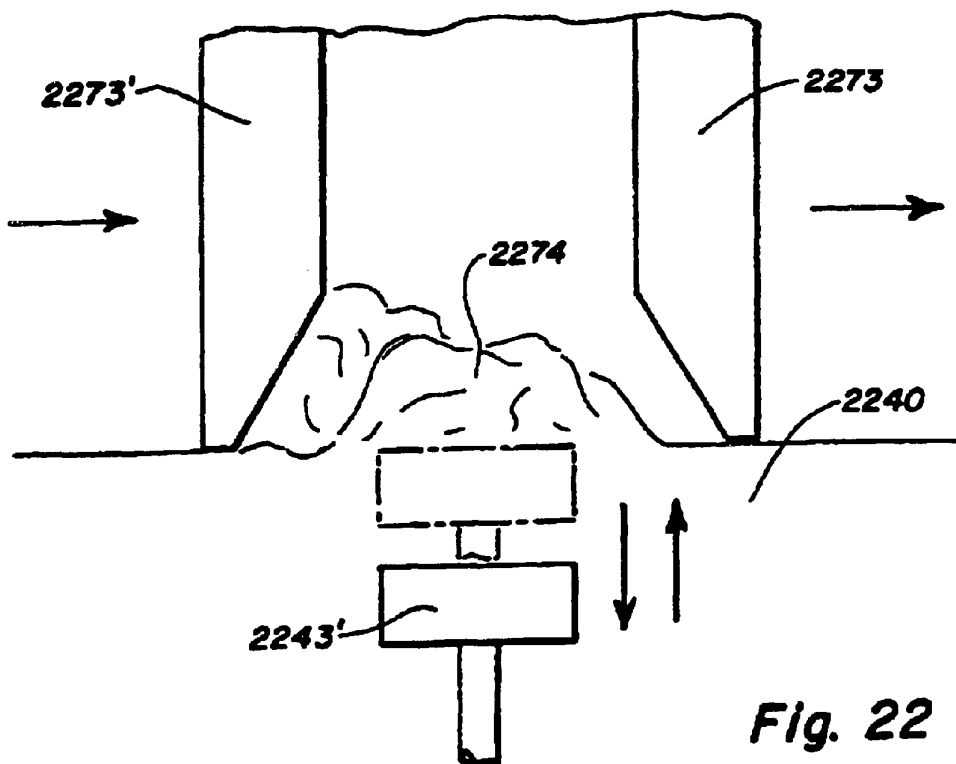


Fig. 22

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**SOLID IMAGING APPARATUS AND
METHOD WITH COATING STATION****CROSS REFERENCE TO RELATED
APPLICATIONS**

The present application is a continuation of application Ser. No. 09/541,025, filed Mar. 31, 2000, now U.S. Pat. No. 6,340,297, which is a continuation of application Ser. No. 08/804,449, filed Feb. 21, 1997 (now U.S. Pat. No. 6,174,156 B1), which is a continuation application Ser. No. 07/884,030, filed May 18, 1992 (now U.S. Pat. No. 5,626,919), which is a continuation-in-part of application Ser. No. 07/804,269, filed Dec. 5, 1991, now abandoned, which is a continuation of application Ser. No. 07/488,095, filed Mar. 1, 1990, now abandoned.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

This invention pertains to a solid imaging method and apparatus for fabricating an integral three-dimensional object from a multiplicity of cross sectional portions of the object. More particularly, the cross sectional portions correspond to solidified portions of contiguous layers of a photoformable composition. The method and apparatus use a dispenser in a coating station, which transfers part of the all photoformable composition over the free surface of the composition so that a doctor blade may produce a uniform liquid layer.

2. Description of Related Art

Many systems for production of three-dimensional modeling by photoforming have been proposed. European Patent Application No. 250,121 filed by Scitex Corporation Ltd., on Jun. 6, 1987, discloses a three-dimensional modeling apparatus using a solidifiable liquid, and provide a good summary of documents pertinent to this art. U.S. Pat. No. 4,575,330, issued to C. W. Hull on Mar. 11, 1986, describes a system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed at a selected surface of a fluid medium capable of altering its physical state in response to appropriate synergistic stimulation by impinging radiation, particle bombardment or chemical reaction. Successive adjacent laminae, representing corresponding successive adjacent cross-sections of the object, are automatically formed and integrated together to provide a step-wise laminar buildup of the desired object, whereby a three-dimensional object is formed and drawn from a substantially planar surface of the fluid medium during the forming process. U.S. Pat. No. 4,752,498, issued to E. V. Fudim on Jun. 21, 1988, describes an improved method of forming three-dimensional objects, which comprises irradiating an uncured photopolymer by transmitting an effective amount of photopolymer solidifying radiation through a radiation transmitting material which is in contact with the uncured liquid photopolymer. The transmitting material is a material which leaves the irradiated surface capable of further crosslinking, so that when a subsequent layer is formed it will adhere thereto. Using this method, multilayer objects can be made.

A publication entitled "Automatic Method for fabricating a three-dimensional plastic model with photohardening polymer" by Hideo Kodama, Rev. Sci. Instrum. 52(11), 1770-1773, November 1981, describes a method for automatic fabrication of a three-dimensional plastic model. The solid model is fabricated by exposing liquid photo-forming polymer to ultraviolet rays, and stacking the cross-sectional solidified layers. A publication entitled "Solid Object Gen-

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eration" by Alan J. Herbert, Journal of Applied Photographic Engineering, 8(4), 185-188, August 1982, describes an apparatus which can produce a replica of a solid or three-dimensional object much as a photocopier is capable of performing the same task for a two-dimensional object. The apparatus is capable of generating, in photopolymer, simple three-dimensional objects from information stored in computer memory. A good review of the different methods is also given by a more recent publication entitled "A Review of 3D Solid Object Generation" by A. J. Herbert, Journal of Imaging Technology 15: 186-190 (1989).

Most of these approaches relate to the formation of solid sectors of three-dimensional objects in steps by sequential irradiation of areas or volumes sought to be solidified. Various masking techniques are described as well as the use of direct laser writing, i.e., exposing a photoformable composition with a laser beam according to a desired pattern and building a three-dimensional model, layer by layer. In addition to various exposure techniques, several methods of creating thin liquid layers are described which allow both coating a platform initially and coating successive layers previously exposed and solidified.

The aforementioned methods of coating, however, are not capable of ensuring flat uniform layer thickness or of producing such layers quickly, or they do not effectively prevent damage or distortion to previously formed layers during the successive coating process and they involve coating only liquid formulations of preferably low viscosity. Furthermore, they omit to recognize very important parameters involved in the coating process such as the effects of having both solid and liquid regions present during the formation of the thin liquid layers, the effects of fluid flow and Theological characteristics of the liquid, the tendency for thin photoformed layers to easily become distorted by fluid flow during coating, and the effects of weak forces such as hydrogen bonds and substantially stronger forces such as mechanical bonds and vacuum or pressure differential forces on those thin layers and on the part being formed.

The Hull patent, for example, describes a dipping process where a platform is dipped below the distance of one layer in a vat, then brought up to within one layer thickness of the surface of the photoformable liquid. Hull further suggests that low viscosity liquids are preferable but, for other practical reasons, the photoformable liquids are generally high viscosity liquids. Motion of the platform and parts, which have cantilevered or beam regions (unsupported in the Z direction by previous layer sections) within the liquid, creates deflections in the layers, contributing to a lack of tolerance in the finished part. In addition, this method is rather slow.

U.S. Pat. No. 2,775,758, issued to O. J. Munz on Dec. 25, 1956, and the Scitex application describe methods by which the photoformable liquid is introduced into a vat by means of a pump or similar apparatus such that the new liquid level surface forms in one layer thickness over the previously exposed layers. Such methods have the aforementioned disadvantages of the Hull method except that the deflection of the layers during coating is reduced.

The patent issued to Fudim describes the use of a transmitting material to fix its the surface of a photopolymner liquid to a desired shape, assumably flat, through which photopolymers of desired thickness are solidified. The transmitting material is usually rigid and either coated or inherently nonadherent to the solidified photopolymer. The methods described by Fudim do not address the problems inherent in separating such a transmitting material from a

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photopolymer formed in intimate contact with the surface of the transmitting material. Whereas the effects of chemical bonding may be reduced significantly by suitable coatings or inherently suitable films, the mechanical bonds along with hydrogen bonds, vacuum forces, and the like are still present and in some cases substantial enough to cause damage or distortion to the photopolymer during removal from the transmitting material surface.

Methods utilizing doctor blades and/or material supply mechanisms have been proposed in such publications as Japanese Patent Application Publication numbers 61-114817, 61-114818, and 61-116322. However, these methods require an exact amount of material or photoformable composition to be added in the vessel every time a layer has to be formed. Also, they require the doctor blade or smoothing blade to have a length equal to the width of the vessel in order to properly operate. Because of this, the systems described in these patents have restrictions necessarily confining the photosensitive material between the doctor blade and part of the vessel at all times. Thus, it becomes very difficult to form a uniform layer in one continuous pass of the doctor blade without ending up with an excess or shortage of material at the end of the pass. In other words, the doctored layer may be either lacking a part of it at the end of one doctoring operation or it may have an excess of material, which will be very difficult to redistribute in order to achieve the proper thickness and uniformity, due to the confined nature of the arrangement. Also, the doctor blade has a tendency to create wave motion in the material surrounding the previously exposed layer causing a disturbing effect, particularly on parts of the previously exposed layer which are partially unsupported.

Thus, it is one of the objects of the present invention to provide an apparatus and a method for fabricating an integral three-dimensional object from a multiplicity of cross sectional portions of the object, the cross sectional portions corresponding to solidified portions of contiguous layers of a photoformable liquid composition, in a fast and uniform manner. Another object of the present invention is to provide a gentle way of raising part of the photoformable composition above the surface of said composition and in front of the doctor blade. Use of a pump to recirculate a liquid of the nature used in solid imaging or stereolithography does not present a viable solution because the viscosity and mainly sensitivity of such compositions cause blockage of the paths and seizure of the pumping operation at an unacceptably high rate. Premature polymerization within the higher-shear components of the pump seem to be the most probable cause of this problem.

SUMMARY OF THE INVENTION

The present invention comprises a solid imaging apparatus and method for fabricating an integral three-dimensional object by selectively exposing successive layers of a liquid photoformable composition to actinic radiation. The apparatus includes a vessel for containing the composition so as to present a free surface, and a movable platform disposed within the vessel below the free surface. Part of the composition is transferred above the free surface by lowering and raising a dispensers at predetermined positions located away from the platform. A doctor blade contacts the composition transferred above the free surface, and then moves over the platform to form a substantially uniform layer of the composition.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view showing a preferred embodiment of this invention.

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FIG. 2 is an elevation view showing a part of the coating station including a dispenser employed in the present invention.

FIG. 3 is an elevation view showing a dispenser for dispensing liquid composition.

FIGS. 4a and 4b are perspective views illustrating the embodiment of FIG. 3.

FIG. 5 is an elevation view showing another embodiment of this invention.

FIG. 6 is a perspective view showing the embodiment of FIG. 5.

FIG. 7 is an elevation view showing another dispenser where a pivoting mechanism is utilized for dispensing the liquid.

FIGS. 8a through 8e are elevation views showing another embodiment of this invention.

FIGS. 9a and 9b are perspective views showing another embodiment of the invention.

FIG. 10 is an elevation view showing a different embodiment of the present invention where the dispenser is in the form of a single plate.

FIG. 11 is an elevation view of another embodiment wherein the dispenser is in the form of parallel blades.

FIG. 12 is an elevation view showing the dispenser as a plate having a plurality of bristles attached to its sides so as to have a brush-like configuration.

FIG. 13a is an elevation view showing still another embodiment of the present invention where the dispenser is in the form of a plate having a plurality of pockets on either side.

FIG. 13b is a perspective view illustrating the embodiment of FIG. 13a.

FIG. 14a is an elevation view illustrating the use of wipers to control the dispensing rate of photoformable composition from a plate-like dispenser.

FIG. 14b is a perspective view illustrating the embodiment of FIG. 14a.

FIGS. 15a and 15b are elevation views illustrating another embodiment of the present invention wherein the doctor blade itself serves as the dispenser.

FIGS. 16a, 16b, 17a, 17b and 18 are elevation views illustrating other embodiments of this invention where the dispenser has been incorporated onto the, front part of the doctor blade.

FIG. 19 is an elevation view illustrating yet a different embodiment of the present invention where the dispenser and the doctor blade have been combined into a single unit.

FIG. 20 is an elevation view showing another embodiment where the dispenser is always disposed in the liquid and pulsates to form a wave in front of the doctor blade.

FIG. 21 is an elevation view showing an additional preferred embodiment where two doctor blades are utilized, with the dispenser located between the two doctor blades.

FIG. 22 is an elevation view showing another embodiment where two doctor blades are utilized with the dispenser located between the two blades.

FIG. 23 is a schematic elevation view showing an embodiment of the present invention for lowering and raising the dispenser shown in FIG. 2 at predetermined positions and time periods.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed to a solid image method and apparatus for fabricating an integral three-

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dimensional object from a multiplicity of cross sectional portions of the object. More particularly, the cross sectional portions correspond to solidified portions of contiguous layers of a photoformable composition. The method and apparatus use a dispenser in a coating station, which transfers part of the photoformable composition over the free surface of the composition so that a doctor blade may produce a uniform liquid layer.

FIG. 1 shows an imaging station or means 70 including a radiation source 10, a modulator 14, a computer 34 and a deflection means 16, preferably in the form of a scanner. There is also provided a coating station 71. Radiation source 10 is preferably a laser, producing a radiation beam 12. In order to produce solid objects at high speed, the imaging station 70 preferably utilizes relatively high power radiation sources 10, such as high power lasers, which may have major bands in the visible, infrared, or ultraviolet regions. For present photospeeds of photoformable compositions, high power is considered to be a power greater than 20 mW, and preferably over 100 mW as measured from the intensity of the radiation beam 12. However, as faster compositions become available, the values of 20 mW and 100 mW for the beam intensity will become lower accordingly, since photospeed of the composition and intensity of the radiation beam have an inverse relation to each other in order to achieve the same results. The selection of a certain type of laser should be coordinated with the selection of the photoformable composition in a way that the sensitivity of the photoformable composition agrees reasonably well with the wavelength of the laser's emission. Other types of radiation means may also be utilized such as electron beams, x-rays, and the like, as long as their energy type is matched with the sensitivity of the photoformable composition, a beam is provided, and the appropriate conditions for their handling are observed according to established ways, well known in the art. Although means may be provided to modify the shape of the beam cross-section to any desirable shape, the ordinary shape is circular, and the profile of the intensity of the beam is gaussian with a maximum at the center of the circular shape.

The radiation beam 12 passes through the modulator 14, preferably an acousto-optical modulator. The modulated radiation beam 12' passes in turn through the deflection means 16 or scanner, which comprises two mirrors 20 and 22, each mirror having an axis (not shown) allowing reflection of the beam to a free surface 46 in X and Y directions, the X and Y directions being perpendicular to each other and parallel to the free surface 46. The mirrors 20 and 22 may rotatably move around their corresponding axes by means of motors 24 and 26, respectively, for controllably deflecting the beam in a vector scanning mode, in the X and Y directions, towards predetermined positions of a photoformable composition 40 contained in a vessel 44 of the coating station 71. As the beam is deflected by the deflection means 16, it assumes an acceleration from zero level to a maximum acceleration, and a velocity from zero level to a maximum constant velocity. The velocity and intensity of the beam remain proportional to each other, so that the exposure remains substantially constant. The beam 12" exposes pre-selected portions of the composition to a substantially constant depth as described below.

For the purpose of this invention, the radiation beam 12" may be not only a focused beam from a laser, but also light from any other light source, modified in a number of different ways. For example, it may be transmitted through any type of variable optical density photomask such as a liquid crystal display, silver halide film, electro-deposited

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mask etc., or reflected off of any variable optical density device, such as a reflective liquid crystal cell. Also, the deflection means may be any other type of scanner, such as a raster scanner, for example.

The coating station 71 comprises a vessel 44 for containing the liquid photoformable composition 40. A substantially flat platform 41 is disposed within the vessel 44 and adapted to be positioned under the free surface 46 of the composition 40. The platform 44 has sides, such as a left L and a right R side. A placement means 42 is provided for controllably varying the distance between the free surface 46 of the composition 40 and the platform 41 through a supporting arm 42'. Although the placement means 42 is shown in FIG. 1 as being fully immersed in the composition 40, it should be understood that it may be preferably positioned outside the vessel, and connected to the platform 41 either by passing the supporting arm 42' through a seal at the bottom of vessel 44, or more preferably by using a bent supporting arm passing around the vessel and through free surface 46 in order to be connected to and support the platform 41. An important part of the invention is a special dispenser 43 located at one side of the platform 41, in front of any type of layering means, and preferably between two doctor blades 73 and 73'. The dispenser 43 is adaptable to be dipped under the free surface 46 of the composition 40 and directly transfer part of the composition 40 above the free surface 46. The transferred part of the composition is used by the doctor blades 73 and 73' to produce a liquid layer 48 on top of the platform 41 or on top of previously photoformed layers. As shown in FIG. 1, communication lines 52, 50, 54, 60, 62, and 63 are also provided for the computer 34 to control the radiation source 10, the modulator 14, the deflection means 16, the placement means 42, the doctor blades 73 and 73', and the dispenser 43, respectively.

In operation of the preferred embodiment of this invention, the radiation means 10 provides a radiation beam 12 having an intensity as aforementioned. The radiation beam 12 passes through a modulator 14, where its intensity may be modulated from a zero intensity level to a maximum intensity level having a value less than that of the unmodulated beam intensity, due to energy losses. The modulated radiation beam 12', having somewhat decreased intensity due to losses, passes in turn through the deflection means 16 having a two-mirror 20 and 22 assembly, each mirror separately driven by a different motor 24 and 26, respectively. Mirror 20 deflects the beam in a X direction, while mirror 22 deflects the beam in a Y direction, the X direction being perpendicular to the Y direction. Electrical feedback regarding the relative movements of the mirrors 20 and 22 is provided by the deflection means 16 to the computer 34 through line 54. This feedback, being correlatable to the velocity and average residence time of the beam 12" on the predetermined portions of the thin layer 48, is processed by the computer 34, and it is fed to the modulation means 14 as a control command through line 50 in order to modulate the intensity of the radiation beam 12, so that the product of the intensity of the beam 12" and the average residence time at each position of the predetermined portions of layer 48 remains substantially constant. Thus, the exposure level, being by definition the product of these two parameters, remains substantially constant. By maintaining the exposure level constant over the predetermined portions of each contiguous thin layer, the thickness of the layers is also kept substantially constant. This correction or compensation is very important, especially at unsupported portions of the thin layers, where swollen edges will appear as a result of overexposure due to the low initial velocity at the edges in

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vector scanning. The higher the intensity of the beam 12", or the higher the photosensitivity of the photoformable composition, the more severe this problem becomes in the absence of means to maintain the exposure level constant. Such exposure control is also necessary in raster scanning or in systems incorporating overscanned vector schemes, the difference being that the edges of the image may be under-exposed due to lack of exposure contribution from adjacent non-exposed regions. In these cases, modulation means are utilized to ensure that edge regions of the image receive substantially the same exposure as non-edge regions. In any event, the radiation beam 12" is controllably directed towards the photoformable composition 40.

The platform 41, which has a substantially flat upper surface 41', is initially placed within the vessel 44 in a way that the flat upper surface 41' is contained within the free surface 46 of the composition 40. In sequence, the platform 41 is lowered in the composition 40 by the thickness of the layer 48. The dispenser 43, which is preferably kept at least partially dipped under the free surface 46 of the photoformable composition 40 when not in motion, is raised and starts dispensing liquid composition 40 between the doctor blades 73 and 73'. The doctor blade 73 then produces a uniform liquid layer 48 on top of the substantially flat surface 41' of platform 41. In FIG. 1, the dispenser 43 is shown to be partially dipped in the composition 40 adjacent the right side R of the platform 41. When the doctor blades 73 and 73' and the dispenser 43 reach the left side L of the platform 41 they stop, and the dispenser 43 is preferably at least partially dipped in composition 40 under the free surface 46. Preferably, the dispenser 43 remains completely dipped at this stage. A short time may be allowed, if necessary, for the free surface 46 to reach equilibrium and assume the desired uniformity. At least a portion of the liquid layer 48 is then exposed imagewise by actinic radiation, which preferably is in the form of the laser beam 12".

After this fast imaging step, the platform 41 is lowered again by the thickness of the layer 48. The dispenser 43, which was now kept partially dipped under the free by surface 46 of the photoformable composition 40 at the left side L of the platform, is raised and starts dispensing liquid composition 40 between the doctor blades 73 and 73'. The doctor blade 73' then produces a uniform liquid layer 48 on top of the platform 41 and previously photoformed layer as the assembly of blades 73 and 73' and dispenser 43 now moves towards the right side R of the platform 41. When the assembly of the doctor blades 73 and 73' and the dispenser 43 reaches the right side R of the platform 41 they stop again, and the dispenser 43 is dipped in the composition 40 under the free surface 46. A short time may be allowed again, if necessary, for the free surface 46 to reach equilibrium and assume the desired uniformity. At least a portion of the liquid layer 48, now being on top of the previously imagewise exposed layer, is exposed imagewise to the laser beam 12a. The above steps are repeated until all contiguous layers have been produced and the three dimensional object has been completed. All the above steps are coordinated by the computer 34 in a conventional manner.

In the present invention, the equilibrium level of the free surface 46 always remains substantially constant, regardless of the distance moved by the platform, because the amount of photoformable composition 40 within the vessel 44 remains the same since no additional composition 40 is added. The composition needed for successive layers 48 is transferred above the free surface 46 by lowering and raising the dispenser 43 at predetermined positions alongside the platform 41. Since the dispenser 43 dips under the free

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surface 46 and directly transfers part of the composition above the free surface 46, the temporary level of the free surface 46 will be lowered, relative to the previous equilibrium level, due to transfer of some of the composition and the dispenser 43 above the free surface 46. However, after the dispenser 43 is again dipped into the composition 40 below this temporary free surface 46, the free surface 46 quickly returns to its equilibrium level. Consequently, the equilibrium level of the free surface 46 will always remain substantially the same, thereby ensuring that the distance between the deflection means 16 and the free surface 46 remains substantially constant. It is critically important that this distance remain substantially constant in order that the laser beam 12" remain focused precisely at the surface 46 of the composition so as to achieve dimensionally photoformed layers. Even though a typical photoformable composition 40 may change in volume upon polymerization by shrinking approximately one (1) percent, in practice such a change in volume is not significant and does not require any fine adjustments in the equilibrium level of the free surface 46 or the adding of additional composition 40, particularly when the mass of the object being fabricated is less than thirty (30) percent of the mass of the composition 40 in the vessel 44. Usually, the mass of the fabricated part is between one (1) and five (5) percent of the mass of the composition in the vessel 44. Du Pont's SOMOS[®] solid imaging materials are sufficiently close to "ideal" such that no fine turning of the equilibrium level of the free surface 46 is necessary during the fabrication process. It is also significant in the present invention that the dispenser 43 allows the temporary level of the free surface 46 to be lowered while the doctor blade 73 moves across the platform 41, so that the doctor blade 73 minimizes any type of wave motion in the composition surrounding the previously exposed layer, thereby preventing any such wave motion from disturbing the previously exposed layer, particularly those parts of the exposed layer which are partially unsupported.

FIG. 2 illustrates the usefulness of the dispenser 43. When the platform 41 is lowered by the thickness of the layer 48, the composition 40 does not form a complete layer on top of previously solidified layers 11. Thus, unless the three dimensional object has very limited dimensions, only a small part of the surface of the most recently solidified layer is covered by the liquid layer 48, while a remaining part 48' of the surface remains uncoated. Any conventional means may be used to lower and raise the dispenser 43 at predetermined positions and time periods. Such means include but are not limited to motors combined with rails in the form of cams, electromagnets, and the like. One example is illustrated schematically in FIG. 23. In the embodiment shown in FIG. 23, a rail cam 2393 is employed to lower and raise the dispenser 2343 under and above the free surface 2346 of the photoformable composition 2340, respectively. The dispenser 2343 is also shown with dotted lines, adjacent the right side R' of the platform 2341, where it has been lowered due to the shape of the rail cam 2393, the path of which is followed by cam follower 2394. It is understood that the dispenser will also be lowered adjacent the left side L', and raised in the intermediate position as shown by the complete lines.

In operation, referring back to FIGS. 1 and 2, the dispenser 43 is dipped into the photoformable composition 40 and then it is raised above the free surface 46 of the composition 40. As soon as the dispenser 43 is raised above the free surface 46 of the composition 40, the composition 40 from the dispenser 43 starts being dispensed in front of the doctor blade 73, preferably by force of gravity. It is very

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important that there be an abundance 74 of the composition 40 in front of the doctor blade 73 so that a complete layer 48 may be formed. To avoid entrapment of air in the form of air bubbles in the abundance 74 of composition 40 in front of the doctor blade 73, it is important that the dispenser 43 be raised only slightly above the free surface 46 of the photoformable composition 40. It has also been found that the continuity of the liquid dispensed as a curtain or extrusion sheet by the dispenser 43 may suffer interruptions and splitting if the distance between the dispenser 43 and the free surface 46 is high. This will depend, however, on the rheological characteristics of the photoformable composition 40, the characteristics of the dispenser 43, and other factors. Thus, it is preferable in general that the dispenser 43 be raised by less than 5 mm, more preferable by less than 2 mm, and even more preferable by between 0.5 mm and 1 mm above the free surface 46 of the composition 40. It should be noted, however, that during dispensing, the gap between the free surface 46 of the composition 40 and the dispenser 43 should be equal to or greater than the gap between the same free surface 46 and the corresponding doctor blade 73.

After the dispenser 43 has been raised, both the dispenser 43 and the doctor blade 73 move forward with the dispenser 43 leading and the doctor blade 73 following. The distance between the previously solidified layers 11 and the doctor blade 73, when the doctor blade 73 is passing above the solidified layers 11, is maintained constant and corresponds to about the thickness of the layer 48. After a full pass, a short time may be allowed for the surface 46 of the composition 40 to stabilize, after which the step of exposing imagewise is performed. The speed of travel of the assembly of dispenser 43 and doctor blade 73 should be lower than a certain limit in order to avoid air entrapment in the form of bubbles. This limit depends on the rheological and foaming characteristics of the photohardenable composition 40. With the photohardenable compositions employed by the applicants, speeds of less than 1 inch per second, and preferably about 0.5 inch per second are adequate to cause only minimal air entrapment.

The dispenser 43 may be shaped like a trough as shown in FIGS. 3, 4a and 4b. It has a slot 80 at the bottom so that liquid can freely run through. Depending on viscosity of the composition 40, the slot 80 can be thinner or wider in order to deliver a proper amount 74 of composition 40 in front of the doctor blade 73. It may also have the form of a plurality of openings in proximity to each other. During the dipping operation, it is preferable that the dispenser 43 is not dipped completely under the free surface 46 of the composition 40, so that the composition 40 enters the dispenser 43 through the slot 80, or in general through the bottom opening in whatever form it might be, and not over the top, in order to avoid air entrapment, especially with compositions of high viscosity. The dipping and raising rates are also important for preventing air entrapment, and should be adjusted depending on the viscosity, surface tension and, in general, the foaming characteristics of the composition 40. As shown in FIGS. 5 and 6, a valve 82 may be incorporated in the design of the dispenser 43 so that it can control the slot 80 according to the desired delivery rate for the composition 40. In this particular example, illustrated in FIGS. 5 and 6, this valve 82 can comprise just a rod which can be moved closer or further away to slot 80 in order to permit more or less material to go through at the desired rate.

In another embodiment of the present invention, illustrated in FIG. 7, the dispenser 743 is connected through a hinge 775 so that when the dispenser 743 is to be dipped, it

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is in an upright position so as to accept the liquid photoformable composition 40 within its cavity; however, when it is raised and ready to deliver the liquid composition, it is pivoted and inclined around hinge 775 as shown in FIG. 7.

FIG. 10 illustrates another embodiment of the invention where the dispenser 1043 in front of the doctor blade 1073 is just a single plate. This arrangement is especially useful when the viscosity of the composition is high enough so that adequate material is attached to blade 1043. The material is then delivered in front of the doctor blade 1073 by force of gravity.

Still another embodiment is shown in FIG. 11, where the dispenser 1143 comprises a plurality of parallel plates connected at the top. This arrangement of the dispenser 1143 allows air to leave the system while it is being immersed into the composition and also allows air to enter system when the composition is being disposed through holes 1183 perforated at the top connecting the parallel plates.

Dispenser 1243, in a different embodiment shown in FIG. 12, may also have the form of a brush so that it can accommodate more liquid.

Still another form of dispenser 1343 is shown in FIG. 13. In this case the dispenser 1343 has the form of a plate with a plurality of pockets 1384 having, preferably, holes 1385 at the bottom of each pocket 1384.

FIGS. 8a through 8e illustrate still another embodiment of this invention. In this embodiment there are two plates 885 and 886, initially substantially parallel to each other. As shown in FIG. 8a, the plates 885 and 886 are initially outside the liquid. Then (FIG. 8b) the plates 885 and 886 are dipped into the liquid, while they are still kept substantially parallel to each other. The reason for this parallel configuration is to avoid turbulence and air entrapment within the composition 840 while the dispenser is being dipped. After the plates 885 and 886 have been dipped into the composition 840 (FIG. 8c), they are pivoted to assume a V shape so that their bottoms meet while the top parts of the plates 885 and 886 still remain open. FIG. 8d shows the plates 885 and 886 in the V position outside the liquid composition 840. This is followed by slightly opening the bottom parts of the plates to form a narrow slot and allow the composition to be dispensed through the slot (FIG. 8e). The configuration of these two plates 885 and 886 is better shown in FIG. 9a and 9b. Plate 885 has two pivoting pins 888 and 888' at the top. Plate 886 has two side walls 887 and 887' which have in their upper corners holes 889 and 889' which are adaptable to receive pivots 888 and 888'. Thus, the two plates 885 and 886 may be assembled in the form of a dispenser, by pivoting plate 885 around pivots 888 and 888', which in turn are inserted in holes 889 and 889', respectively. The plate 885 may seal the dispenser by closely contacting the walls 887 and 887'. In this configuration, if so desired, a slot may be formed at the bottom of the plates, or the plates may be arranged to be substantially parallel to each other, or the whole device can be in a closed position and not allow liquid to pass through, when the bottoms of the plates are brought into contact. Leakage of small amounts of liquid through the walls of the plate 886 and the sides of the plate 885 is not of consequence in most instances. Gasketing materials may be used on the sides and bottom of the plate 885, and/or the walls and bottom of the plate 886, if desired, for better sealing. The walls 889 and 889' may be replaced by a flexible or elastic material for connecting the sides of the two plates in a substantially liquid-proof manner. Any conventional mechanism may be used for opening and closing the blades. Such mechanisms may include but are not limited to

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bars, wires, and the like, connected to the plate **885** for controllably changing the position of one plate with respect to the other.

FIGS. **14a** and **14b** illustrate an additional embodiment of this invention, where the dispenser **1443** is in the form of a plate. Wipers **1492** and **1492'** are provided to controllably dispense picked-up composition by wiping such composition downward. Thus, when the plate **1443** has been dipped and raised in front of the doctor blade (the doctor blade is not shown in FIG. **14a** for clarity purposes), the wipers **1492** and **1492'** start moving downward at a desired rate, preferably controlled by the computer **34**. Similar results may be achieved by holding the wipers **1492** and **1492'** at a constant distance from the free surface **46** of the composition **40**, and raising the dispenser plate **1443** at a desired rate. Of course, this rate may be variable to better fit the dispensing requirements of the particular case. FIG. **14b** shows a perspective view of the dispenser **1443** in plate form in combination with one of the wipers **1492'**.

As shown in FIGS. **15a** and **15b**, the doctor blade itself **1573** can be used also as a dispenser. The doctor blade **1573** is dipped into the composition **1540** and then it is raised to its initial position over the free surface of the photoformable composition, as shown in FIG. **15a**. Since the doctor blade is going to form the coating by moving in the direction of arrow **A**, it is desirable to have a wiper **1592** which moves down and wipes off the excess composition gathered on the back side of the doctor blade **1573**. This is to avoid dragging any material behind the doctor blade **1573** and destroying the uniformity of the produced layer. FIG. **15a** shows the wiper **1592** taking off the excess composition. FIG. **15b** shows the same doctor blade **1573** after it has already started doctoring and leveling a layer **1548** of photoformable composition **1540**, while the wiper **1592** has been lowered and positioned around the free surface of the photoformable composition **1540**. A different way to minimize accumulation of excessive amounts of composition on the back side of the doctor blade **1573** is to dip the blade as it is moving, preferably at an angle smaller than 90 degrees, which increases with time and finally assumes a value of substantially 90 degrees before the doctor blade moves on top of the photoformed layers. This angle is the angle formed between the plane substantially containing the front side of the doctor blade and the plane substantially containing the free surface (FIG. **1**) of the photoformable composition.

The dispenser **1643** shown in FIGS. **16a** and **16b** may be part of the doctor blade **1673** and located in the front part of the doctor blade **1673**. The wiper **1692** performs the same task as described in previous embodiments. FIG. **16b** illustrates the doctor blade **1673** after it has been moved from its initial position, and also shows the wiper **1692** in its lower position.

The front of the doctor blade **1743**, as shown in FIGS. **17a** and **17b**, may have pockets similar to the ones shown in FIGS. **13a** and **13b** for the dispenser **1743**. According to this embodiment, the doctor blade **1743** is dipped into the composition and then raised while the wiper **1792** is stationary near the free surface of the photoformable composition so as to immediately wipe off any excess material on the back part of the blade **1743**. It should be understood that the embodiments already described or the ones described below can be combined in part or in whole. For example, in any of these embodiments the wiper may be either stationary or movable.

Another embodiment, shown in FIG. **18**, illustrates the dispenser **1843** being part of and located in front of the

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doctor blade **1873**, while the wiper **1892** is stationary and at the bottom of the doctor blade **1873** when the blade **1873** is in its initial position.

In still another embodiment illustrated in FIG. **19**, the dispenser **1943** and the doctor blade **1973** can be combined into a unit having a common dispensing tip **1995** at the bottom of the combined device. In FIG. **19**, this combined device is shown while it is providing a layer, while the wiper **1992** has already wiped the back of the device and is in a lowered position.

FIG. **20** shows still another embodiment where the dispenser **2043** is in the form of a plate which is continuously dipped into the composition **2040**. The dispenser **2043** is provided with a pivot **2075** around which the plate may give an upward pulse. Just before the doctor blade **2073** starts its movement for producing a layer, the dispenser **2043** provides an upward pulse and produces an abundance of material **2074** in the form of a wave in front of the doctor blade **2073**. Frequently, this amount of material is adequate for a complete layer to be formed. This embodiment works at its best when the platform and the three-dimensional object to be formed are not excessively large.

Two doctor blades **2173** and **2173'** may be used, one on each side of the dispenser **2143**, as illustrated in FIG. **21**, so that a new layer may be produced regardless of the direction in which the doctor blade/dispenser assembly moves. When the assembly moves in the direction of the arrows **A**, the abundance of material is gathered mainly in front of the blade **2173**, and a new layer is formed behind the blade **2173**. Similarly, when the assembly moves in a direction opposite to that of the arrows **A**, the abundance of material is gathered mainly in front of the blade **2173'**, and a new layer is formed behind the blade **2173'**. It is important that when the assembly stops on either side of the platform, the dispenser is dipped in the liquid, composition **2140** to be refurnished with a new amount of photoformable composition **2140** for the next cycle, in the opposite direction.

The embodiment illustrated in FIG. **22** also involves a double doctor blade arrangement (**2273** and **2273'**) similar to that shown in FIG. **21**, except that the dispenser **2243'**, in this case, is always disposed in the liquid photoformable composition **2240**. There is one dispenser **2243'** on one side of the platform and one dispenser **2243** (not shown) on the other side of the platform. Their position is located within the composition **2240**, and under the "stop" positions of the doctor blades on either side of the platform. Just before the doctor blades start their travel, the respective dispenser moves quickly upward and forces an abundance of liquid to gather between the two doctor blades. The rest of the operation is substantially the same as in the other embodiments.

In the cases where the dispenser and the doctor blade are separate units, it is often desirable to dip the dispenser in a particular manner. For example, as shown in FIG. **2**, it is often preferable to dip the dispenser **43** at position **P2** while the initial position of the doctor blade **73** is on the other side of the platform at position **P1**. According to this option, the dispenser **43** is moved over to position **P2**, it is dipped at this position in order to receive an adequate amount of composition, then it is raised and brought back in front of the doctor blade **73** at position **P1**. During this movement, the dispenser **43** may continue delivering material over the platform area. On other occasions where the delivery of material can be controlled, such as in the embodiments shown in FIGS. **5**, **6**, **7** or **8**, it may be desirable for the dispenser to start dispensing composition only when it is in

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front of the doctor blade 73 at position P1 and at the same time that the doctor blade 73 is forming the layer. This version of operation may be desirable when higher accuracy and speed are needed since the material received by the dispenser 43 at position P2 is going to be moved back by the doctor blade 73.

In most cases it is desirable for the dispenser 43 to be in the dipped position while exposing the layer, so that material still held by the dispenser will be in the container and will not change the level of the free surface of the composition and of the layer. As mentioned before, it is important for the dispensed liquid to be very close to the free surface of the composition in order to avoid splashing and entrapment of air in the form of bubbles. Of course, one can work under vacuum, thereby making the height at which the dispenser operates immaterial.

Since all these devices are controllable by a computer, one can arrange the delivery cycle as well as their speed of operation in order to obtain maximum efficiency and uniformity. Depending on the viscosity and other properties of the photoformable liquid composition, somewhat different conditions may be needed to obtain optimal results. Sensors such as ultrasonic, infrared, and the like may be used to give feedback to the computer regarding the build-up in front of the doctor blade and regulate, accordingly, the delivery through the above mechanism.

The photoformable compositions which can be used in the practice of the instant invention are any compositions which undergo solidification under exposure to actinic radiation. Such compositions comprise usually but not necessarily a photosensitive material and a photoinitiator. The word "photo" is used here to denote not only light, but also any other type of actinic radiation which may transform a deformable composition, preferably a liquid, to a solid by exposure to such radiation. Cationic or anionic polymerizations, as well as condensation and free radical polymerizations and combinations thereof are examples of such behavior. Cationic polymerizations are preferable, and free radical polymerizations even more preferable. Photoformable compositions containing thermally coalescible materials are of even higher preference.

A liquid thermally coalescible photoformable composition is a composition which solidifies upon exposure to actinic radiation without attaining necessarily its ultimate physical properties, particularly with respect to their adhesive and cohesive characteristics. However, it develops adequate integrity to be handled until such time when further treatment is provided. The composition is considered as coalescible when it comprises particulate matter in dispersed form, which particulate matter undergoes coalescence under a certain set of conditions, such as increased temperature for example. Coalescence is the transformation of a dispersed phase to a cohesive continuous solid phase.

Preferably the photoformable composition comprises a thermally coalescible polymeric cohesive material, a photoformable monomer, and a photoinitiator. Preferably the photoformable material comprises an ethylenically unsaturated monomer. Upon exposure to the actinic radiation, the exposed areas of the photoformable composition must remain thermally coalescible after removing the unexposed areas. This is important to improve both adhesion in the joining surfaces between the layers and cohesion within the layers for a multilayer integral three dimensional object. Actually, cohesive bonds are formed at the joining surfaces by the thermally coalescible material, providing superior properties to the structure of the final three dimensional

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object. It is also very important to prevent substantial overgrowth of infra posed surfaces, as it will be discussed below.

In the case of photoformable compositions which are not based on coalescible materials, post treatment after the exposure step is not required. In the case where a coalescible material is an essential component of the formulation, further heat treatment is needed for the object to attain its ultimate strength. In such cases, when all the layers of the three dimensional object have been formed by the method described above, the unexposed portions of the composition may be removed by any conventional means, such as shaking the object, blowing gas towards the object, and the like. Further removal may be achieved by rinsing the object with poor, noncoalescing solvents. Water, alcohols, and in general polar solvents are poor solvents for non-polar compositions and vice-versa. As long as the solvent under consideration does not extract excessive amounts of materials from the exposed area or cause the object being rinsed to swell within the rinsing time, it is considered to be a poor, non-coalescing solvent. The object then is thermally coalesced in order to develop high cohesive and adhesive strength. This step may be performed in an oven, such as a convection, IR or microwave oven. Optimum temperature and time are dependent on the individual composition. Typically the temperature range is 100°–250° C. and the time range is 5–30 minutes. However, temperature and times outside these regions may be used.

A very important group of thermally coalescible materials are plastisols. Plastisols are fluid mixtures, ranging in viscosity from pourable liquids to heavy pastes, obtained by dispersing fine particle size polymeric resins in nonvolatile liquid thermal plasticizers, i.e., materials which are compatible with the polymer or resin and increase its workability and flexibility but have no substantial solvent activity for the resin or polymer under ordinary conditions of storage (e.g. room conditions). When the plastisol has been formed into a desired shape, e.g., by molding or coating, it can be heated to coalesce the polymeric resin particles and the nonvolatile liquid constituent, thereby forming a homogeneous solid mass. Volatile diluents can be added to plastisol dispersions to modify their viscosity and to achieve desirable handling characteristics in coating or other forming operations.

A dispersion that contains no more than 10% volatile diluent is regarded as a plastisol. Since the plasticizer used in the case of plastisols acts as a plasticizer to solvate the polymer only at temperatures higher than storage temperatures, it may also be called a thermal plasticizer. The most widely used plastisols on a polyvinyl chloride homopolymer in a plasticizer.

The following photohardenable composition was made by mixing thoroughly the following ingredients:

1. Ethoxylated Trimethylol Propane Triacrylate	75.0 g
2. Urethane Acrylate Resin (Sartomer 9610)	75.0 g
3. 2,2-dimethoxy-2-phenylacetophenone	6.0 g
4. Clear Chem-o-sol ® 7557 (made by Whittaker Corp. Providence Chemical Division, East Providence, RI)	225.0 g

An automobile distributor cap of excellent quality was made by using this photohardenable composition, and the method and apparatus as described hereinabove. The double

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doctor blade arrangement with the dispenser as shown in FIG. 21 was used. When the dispenser was at rest on either side of the platform, it was maintained completely immersed under the free surface of the photohardenable composition. During dispensing at the raised position, the dispenser was 1 mm above the free surface of the composition. The slot width was approximately 0.190 inch and the travelling speed 0.5 inch per second. Only a minimal amount of bubbles were observed on the free surface of the composition. No interruptions occurred on either the dispensed liquid or on the layers, which were 0.015 inch thick. After the distributor top was photoformed it was thermally treated in a convection air oven at 165° F. for 15 minutes for the part to achieve its ultimate strength. It should be noted that when the dispenser was raised more than 5 mm above the free surface of the composition, the dispensed liquid in the form of a curtain had interruptions along its width resulting in inadequate coverage of previously photoformed layers.

What is claimed is:

1. A solid imaging apparatus, said apparatus including:

- (i) a vessel containing a photoformable composition;
- (ii) a movable platform disposed within said vessel;
- (iii) a sub-assembly comprising a movable dispenser, said movable dispenser defining an opening;

wherein said sub-assembly is adapted to both receive and deposit part of said photoformable composition through said opening.

2. The apparatus of claim 1, wherein said opening is a downwardly facing elongated slot.

3. The apparatus of claim 1, wherein said movable dispenser is adapted to deposit part of said photoformable composition above said platform.

4. The apparatus of claim 1, wherein said apparatus further comprises a radiation source capable of curing said photoformable composition.

5. The apparatus of claim 1, wherein said dispenser comprises a pair of plates that hold the lifted composition therebetween.

6. The apparatus of claim 1, wherein said dispenser includes a holding mechanism that holds the lifted composition above the surface of said photoformable composition in the vessel.

7. The apparatus of claim 1, wherein the dispenser includes a blade with an edge positioned at the surface of said photoformable composition in the vessel.

8. The apparatus of claim 1, wherein said dispenser includes a blade with a holding mechanism that holds lifted composition against a surface of the blade.

9. The apparatus of claim 1, wherein the dispenser includes a pair of plates that form a holding chamber therebetween, wherein a portion of the composition is retained within the chamber while another portion of the composition is allowed to flow from the chamber by force of gravity.

10. A solid imaging system comprising:

- (a) a photoformable composition including free radical polymerizable material; and

- (b) an apparatus including

- (i) a vessel for containing said photoformable composition;
- (ii) a movable platform disposed within said vessel;
- (iii) a sub-assembly comprising a movable dispenser, said movable dispenser defining an opening;

wherein said sub-assembly is adapted to both receive and deposit part of said photoformable composition through said opening.

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11. The system of claim 10, wherein said opening is a downwardly facing elongated slot.

12. The system of claim 10, wherein said movable dispenser is adapted to deposit part of said photoformable composition above said platform.

13. The system of claim 10, wherein said apparatus further comprises a radiation source capable of curing said photoformable composition.

14. The system of claim 10, wherein said dispenser comprises a pair of plates that hold the lifted composition therebetween.

15. The system of claim 10, wherein said dispenser includes a holding mechanism that holds the lifted composition above the surface of said photoformable composition in the vessel.

16. The system of claim 10, wherein the dispenser includes a blade with an edge positioned at the surface of said photoformable composition in the vessel.

17. The system of claim 10, wherein said dispenser includes a blade with a holding mechanism that holds lifted composition against a surface of the blade.

18. The system of claim 10, wherein the dispenser includes a pair of plates that form a holding chamber therebetween, wherein a portion of the composition is retained within the chamber while another portion of the composition is allowed to flow from the chamber by force of gravity.

19. The system of claim 10, wherein said composition further comprises cationically polymerizable material.

20. The system of claim 10, wherein said free radical polymerizable material includes ethoxylated trimethylolpropane triacrylate.

21. The system of claim 18, wherein said free radical polymerizable material includes ethoxylated trimethylolpropane triacrylate.

22. The system of claim 10, wherein said composition comprises thermally coalescible polymeric cohesive material.

23. A solid imaging system comprising:

- (a) an apparatus; and

- (b) a photoformable composition adapted for use in said apparatus;

wherein

said composition comprises

- (i) an ethylenically unsaturated monomer; and

said apparatus comprises

- (i) a vessel for containing said composition;
- (ii) a movable platform disposed within said vessel;
- (iii) a sub-assembly comprising a movable dispenser, said movable dispenser defining an opening, said sub-assembly being adapted to both receive and deposit part of said photoformable composition through said opening; and
- (iv) a radiation source capable of curing said photoformable composition.

24. The system of claim 23, wherein said dispenser includes a holding mechanism that holds the lifted composition above the surface of said photoformable composition in the vessel.

25. The system of claim 23, wherein the dispenser includes a pair of plates that form a holding chamber therebetween, wherein a portion of the composition is retained within the chamber while another portion of the composition is allowed to flow from the chamber by force of gravity.

26. The system of claim 23, wherein said composition further comprises cationically polymerizable material.

27. The system of claim 23, wherein said free radical polymerizable material includes ethoxylated trimethylolpropane triacrylate.

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28. The system of claim 23, wherein said composition further comprises thermally coalescible polymeric cohesive material.

29. A solid imaging system comprising:

- (a) an apparatus; and
- (b) a photoformable composition adapted for use in said apparatus;

wherein

- said composition comprises
 - (i) free radical polymerizable material; and
- said apparatus comprises
 - (i) a vessel for containing said composition;
 - (ii) a movable platform disposed within said vessel;
 - (iii) a sub-assembly comprising a movable dispenser, said movable dispenser defining an opening, said

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sub-assembly being adapted to both receive and deposit part of said photoformable composition through said opening; and
(iv) a radiation source capable of curing said photoformable composition;
wherein said dispenser includes a holding mechanism that holds the lifted composition above the surface of said photoformable composition, said holding mechanism including a pair of plates that form a holding chamber therebetween, wherein a portion of the composition is retained within the chamber while another portion of the composition is allowed to flow from the chamber by force of gravity.

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